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ANALYSIS OF DRIVER GAP ACCEPTANCE BEHAVIOUR USING A DISCRETE CHOICE MODEL

BY

Mona I. Abou-Henaidy

A thesis submitted to

the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

DEPARTMENT OF CIVIL ENGINEERING

EDMONTON, ALBERTA

Spring 1994

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FACULTY OF GRADUATE STUDIES AND RESEARCH

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DEDICATION

To my parents, my husband, Mohamed

and

my children, Karim and Ranya

ABSTRACT

The objective of this research was to enhance the understanding of driver gap acceptance behaviour. It aimed to identify factors that affect the behaviour with emphasis on their degree of influence. This understanding is important for the study of intersection capacity, delay, and accident risk.

The scope of this research was limited to unsignalized T-intersections with a focus on left turning movement from a major street into a minor street.

The gap acceptance problem was considered as a series of consecutive choice situations. For a certain available gap between opposing vehicles in the major street, a left-turning driver must decide whether to accept or reject that gap. The probability of accepting or rejecting a gap was investigated using a binary logit model that considers gap attributes and driver characteristics.

Data required for model estimations were collected from five urban and suburban intersections in Edmonton, Canada. Observations included 3,434 left turning drivers accepting or rejecting gaps between 13,067 main stream through vehicles during a total of over 20 hour observation periods.

A sequence of 40 model specifications that include different combinations of factors that may affect a driver's decision, were estimated and analyzed. The final two models were used to determine the relative importance of the studied factors.

Results of data analysis and model estimations indicated that gap size, gender of the driver, presence of passengers in the turning vehicle, and queue delay are important factors in the decision-making process. The decision to accept a gap is also influenced by type of the opposing vehicle, flow rate of opposing traffic, and the presence of vehicles behind the turning vehicle. It was also found that for front delay shorter than 30 seconds the probability of accepting a gap decreases, but increases after that. The speed of opposing vehicles requires further investigation. Results also suggested that the time gap itself is a sufficient surrogate for speed, space gap, and type of opposing vehicle.

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TABLE OF CONTENTS

Page

CHAPTER 1 INTRODUCTION 1

1.1 Problem Statement 1

1.2 Research Objective 3

1.3 Research Framework 3

1.4 Scope and Limitations of the Research 5

1.5 Organization of the Dissertation 6

1.6 Terminology 7

CHAPTER 2 LITERATURE REVIEW 11

2.0 Introduction 11

2.1 Major Gap Acceptance Investigation Methods 11

2.1.1 Critical Gap Method 12

2.1.2 Available Gaps (headway) Distribution Method 18

2.1.3 Fitting Known Mathematical Distribution to Gap Acceptance Data 20

2.1.4 Choice Based Models 22

2.1.5 Other Methods 27

2.2 Factors Affecting Gap Acceptance 28

2.3 Methods of Collecting Gap Acceptance Data 38

2.4 Other Previous Related Research 38

2.5 Summary 38

CHAPTER 3 RESEARCH METHODOLOGY 40

3.0 Introduction 40

3.1 Description of the Problen Studied 40

3.2 Discrete Choice Theory 42

3.2.1 The Principle of Utility Maximization 42

3.2.2 Binary Choice Model 43

3.2.3 Binary Logit Model 46

3.3 Model Specifications 47

3.3.1 Variables Included in Model Specifications 47

3.3.2 Model Specifications Initially Considered 49

3.4 Model Estimation 51
3.4.1 Introduction 51
3.4.2 Maximum Likelihood Estimation Technique 51
3.4.3 Description of the Estimation Program 52
3.5 Model Calibration 54
3.5.1 Informal Tests 55
3.5.2 Statistical Tests 55
3.6 Summary 60

CHAPTER 4 DATA COLLECTION 61
4.0 Introduction 61
4.1 Required Data 61
4.2 Study Locations 62
4.2.1 Site Selection Criteria 62
4.2.2 Description of Study Locations 63
4.3 Data Collection Process 73
4.3.1 Pilot Survey 73
4.3.2 Description of Data Collection Process 74
4.3.3 Practical Experience From Data Collection 81
4.3.4 Special Observations at the Studied Location 82
4.3.5 List of Worksheet Data File 82
4.4 Summary 83

CHAPTER 5 DATA ANALYSIS 85
5.0 Introduction 85
5.1 Calculation of Variables Required for Modelling 85
5.1.1 Example of Variables Calculation 87
5.2 Analysis of Data 93
5.2.1 Left Turning Traffic 93
5.2.2 Opposing Through Traffic 97
5.2.3 Queue Delay 97
5.2.4 Front Delay 101
5.2.5 Time Gap (Headway) 103
5.2.6 Speed of Opposing Vehicles 104

5.2.7 Number of Rejected Gaps 106
5.2.8 Variation of Variables 107
5.2.9 Gap Acceptance 108
5.2.10 Gap Situations 116
5.2.11 Correlation Coefficients Between Study Variables 118
5.3 Summary 120

CHAPTER 6 RESULTS AND DISCUSSION 121
6.0 Introduction 121
6.1 Model Development Process 121
6.2 Initial Model Formulations 126
6.3 Examining the Non-Linearity of the Effect of Front Delay 132
6.3.1 Data Coding 133
6.3.2 Model Estimations 133
6.4 Examining the Non-Linearity of the Effect of Number of Rejected Gaps 137
6.4.1 Coding Number of Rejected Gap Variables 137
6.4.2 Model Estimations 140
6.4.3 Comparison Between the effect of Front Delay and Number of Rejected Gaps 143
6.5 Examining the Effect of Time Gap and Space Gap 144
6.6 Investigation of Behaviour During Peak Hours and Off-Peak Hours 148
6.7 Investigation of Queue Dealy and Front Delay Impact 151
6.7.1 Comparison of Experiencing Queue Delay and Front Delay to No Delay 152
6.7.2 Comparison of Experiencing Queue Delay to Fdelay 155
6.8 Investigation of Number of Lanes, Approach Width, and Location Specific Constants 155
6.9 Further Investigation of Front Delay 158
6.10 Individual Variables and Their Importance 166
6.11 Summary 177

CHAPTER 7 FINDINGS AND CONCLUSIONS 178
7.1 Main Findings 178
7.1.1 Findings From Data Analysis 178

7.1.2 Findings From Model Estimations 180
7.2 Conclusions 184
7.2.1 General Conclusions 184
7.2.2 Evaluation of Data Collection Technique 185
7.2.3 Evaluation of Research Method 185
7.2.4 Practical Application 186
7.3 Future Research 186

REFERENCES 188

APPENDIX A 194
APPENDIX B 204
APPENDIX C 213
APPENDIX D 221

LIST OF TABLES

Table		Page
2.1	Critical Gap Criteria for Unsignalized Intersections	15
3.1	Factors Used in Model Specifications and Their Description	48
3.2	Description of Data File Required for Model Estimation by Logit Program	54
4.1	Directions of Left Turning Movement at the Study Locations	65
4.2	List of the Selected Locations and Observation Periods	76
4.3	List of Worksheet Data File	83
4.4	Summary of Video Taping Duration and Numbers of Observed Left Turning Drivers and Through Vehicles	84
5.1	Example of Left-Turning Vehicle Data	86
5.2	Example of Through Vehicle Data	88
5.3	Summary of Attributes of Gaps and Driver Characteristics for Left Turning Vehicle Number 27	92
5.4	Characteristics of Left Turning Traffic at Each Location	94
5.5	Number of gap situations Involving Each Characteristic of Left Turning Traffic	95
5.6	Classification of Opposing Through Traffic	98
5.7	Number of gap situations Involving Each Type of Opposing Vehicle	99
5.8	Number and Percentage of Drivers experiencing Different Ranges of Front Delay	102
5.9	Minimum, Maximum and Mean Values for Different Variables at Each Location	108
5.10	Number Drivers Incurring Different Values of Front Delay	115
5.11	The Maximum Rejected and the Minimum Accepted gaps at Each Location	117
5.12	Correlation Coefficients Between Study' Variables	119
6.1	Average Values of Variables Used in the Model Estimations	122
6.2	Results of Different Model Estimations Considered in the Initial Stage of Model Development	123
6.3	Number of Choice Situations Involving Each Front Delay Ranges	132
6.4	Examining the Non Linearity of Front Delay Effect	134

6.5 Number of Choice Situations Involved Each Range of Number of Rejected Gaps 140
6.6 Examining the Non-linearity of the Effect of Number of Rejected Gaps 141
6.7 Examining the Effect of Space Gap and Time Gap 145
6.8 Peak Versus Off-Peak Hours Model 149
6.9 Average Values of Variables Used for Model Estimations Described in Table 6.8 150
6.10 Effect of Different Experience of Queue Delay and Front Delay 153
6.11 Investigation of Approach Width, Number of Lanes, and Location Specific Constants 156
6.12 Different Model Specification for Further Investigation of Front Delay (Part 1) 159
6.13 Different Model Specification for Further Investigation of Front Delay (Part 2) 161
6.14 Relative Value of Parameters to Value of Space Gap 167
6.15 Relative Value of Parameters to Value of Time Gap 167
C.1 Example of Input Data File to Logit Estimation Program 219
C.2 Group Identification Numbers for Each Observation Period 220
D.1 The t-statistics of the Null Hypothesis of Linear Relationship Between Front Delay Parameters of Model 2 in Table 6.12 222
D.2 The t-statistics of the Null Hypothesis of Linear Relationship Between Front Delay Parameters of Model 3 in Table 6.12 223
D.3 The t-statistics of the Null Hypothesis of Linear Relationship Between Front Delay Parameters of Model 5 in Table 6.12 224
D.4 The t-statistics of the Null Hypothesis of Linear Relationship Between Front Delay Parameters of Model 7 in Table 6.13 224
D.5 The t-statistics of the Null Hypothesis of Linear Relationship Between Front Delay Parameters of Model 8 in Table 6.13 225
D.6 The t-statistics of the Null Hypothesis of Linear Relationship Between Front Delay Parameters of Model 9 in Table 6.13 226

LIST OF FIGURES

Figure		Page
1.1	Traffic Movements at T-Intersection	2
1.2	System Approach Applied in This Research	4
2.1	Distribution of Accepted and Rejected Lags and Gaps at Intersection Left Turns	12
2.2	Pearson Type III	18
2.3	Probit Regression lines for Estimating Difference in Acceptance Time for Various Movements	21
2.4	Logit Method Plot for Five-Axle Trucks	26
2.5	Effect of Gender of Passengers on the Mean Waiting Time	30
3.1	Description of Gap Acceptance Problem	41
3.2	Different Model Specification Initially Considered	50
4.1	Locations of The Studied Intersections	64
4.2	Layout of 23 Avenue and 110 Street Intersection	66
4.3	Layout of 99 Street and 66 Avenue Intersection	68
4.4	Layout of Fox Drive and Keillor Road Intersection	69
4.5	Layout of West Edmonton Mall Intersection	71
4.6	Layout of Stony Plain Intersection	72
5.1	Distribution of Queue Delay at Different Study Locations	100
5.2	Distribution of Queue Delay Equal to or Less Than t, at Different Study Locations	100
5.3	Distribution of Front Delay at Different Study Locations	101
5.4	Distribution of Front Delay Equal to or Less Than t, at Different Study Locations	102
5.5	Time Gap (Headway) Distribution	103
5.6	Distribution of Time Gap (Headway) Greater Than or Equal to t, at the Study Location	104
5.7	Speed Distribution at Study Locations	105
5.8	Cumulative Speed Distribution at Study Locations	105
5.9	Distribution of Number of Rejected Gaps	106
5.10	Cumulative Distribution of Number of Rejected Gaps	107

5.11 Gap Acceptance Distribution 109
5.12 Cumulative Distribution of Gap Acceptance 109
5.13 Comparison of Lag and Gap Acceptance Distributions 110
5.14 Distribution of Gaps Accepted by Drivers With Different Ranges of Front Delay 111
5.15 Effect of Front Delay on Size of Accepted Gap 112
5.16 Effect of Front Delay on Average Number of Longer Gaps previously Rejected 114
5.17 Average Size of Gap Accepted by Different Categories of Drivers at Different Values of Front Delay 114
5.18 Cumulative Distributions of Gaps Accepted by Drivers Who Accepted a Shorter Gap than Previously Rejected and Drivers Who Waited for a Longer Gap 115
6.1 Summary Results of Initial Model Estimation 131
6.2 Distribution of Number of Rejected Gaps for Front Delay Range between 0 - 15 Seconds 138
6.3 Distribution of Number of Rejected Gaps for Front Delay Range between 15 - 30 Seconds 138
6.4 Distribution of Number of Rejected Gaps for Front Delay > 30Seconds 139
6.5 Influence of Driver Gender on the Gap Acceptance 169
6.6 Influence of Driver Age on the Gap Acceptance 170
6.7 Influence of Presence of Passengers on the Gap Acceptance 171
6.8 Influence of Acceleration Capability on the Gap Acceptance 172
6.9 Effect of Front Delay on the Size of the Accepted Gap 174
6.10 Influence of Type of Opposing Vehicle on the Gap Acceptance 176
B.1 Camera Location at 23 Avenue and 110 Street Intersection 205
B.2 Camera Location at 99 Street and 66 Avenue Intersection 206
B.3 Camera Location at 99 Street and 66 Avenue Intersection 207
B.4 Camera Location at Fox Drive and Keillor Road Intersection 208
B.5 Camera Location at Fox Drive and Keillor Road Intersection 209
B.6 Camera Location at West Edmonton Mall Intersection (WEM) 210
B.7 Camera Location at West Edmonton Mall Intersection (WEM) 211
B.8 Camera Location at Stony Plain Intersection 212

CHAPTER 1

INTRODUCTION

1.1 PROBLEM STATEMENT

A transportation system must be designed to match users' needs and their abilities. As important components of the transportation system, intersections have several manoeuvers arriving from different directions that compete for the available space. The flow of these traffic manoeuvers through these intersections greatly affects the flow on the transportation network. Intersections can be classified into the following categories according to the type of traffic control:

1- Intersections controlled by traffic signals
2- Intersections controlled by traffic signs (Unsignalized intersection)
3- Uncontrolled intersections

Unsignalized intersections are the most common intersection types and are the most complex to analyze (Kittelson and Vandehey, 1991). The most complicated intersection shape to analyze is the multi-leg intersection, and the least complicated is the three-leg intersection (T-intersection). At T-intersections, as shown in Figure 1, the most difficult manoeuver to complete is the left turn movement from a minor street into the major street (movement 3), because drivers have to deal with the conflicting traffic streams from both directions. The left turn from the major street into the minor street (movement 5), is the simplest manoeuver because drivers have to deal with only one conflicting traffic stream (stream 1). The most important factor drivers consider in making their decisions is the availability of a gap between two vehicles in the conflicting stream that is adequate to complete the manoeuver. While drivers are deciding whether to accept or reject a gap, they usually compare the perceived level of risk of being involved in an accident, to the perceived benefits of travel time reduction. This phenomenon is referred to as gap acceptance.

Driver gap acceptance behaviour plays an important role in defining how unsignalized intersections operate. How individual drivers react to conflicting traffic

affects the capacity of an intersection, safety of drivers and passengers, and delay occurring to vehicles joining or crossing a traffic stream.

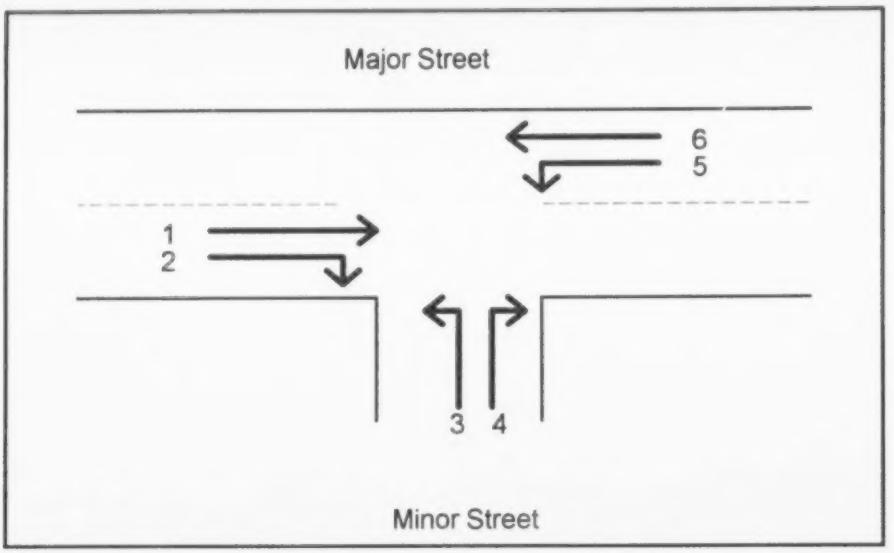

Figure 1.1 Traffic Movements at T-Intersection

Capacity, delay, and safety evaluations have traditionally employed methods based mainly on applications of the gap acceptance phenomenon. In simulation studies, it has been necessary to incorporate into the simulation models some parameters describing the gap acceptance characteristics of the crossing / merging vehicles. The simulation programs are used for evaluating different design alternatives (for example, warrants for the use of stop signs versus traffic signals). These programs estimate delay, stops, queue length, fuel consumption, and other measures of traffic operation at unsignalized intersections.

The number and variety of factors that are mentioned in literature to influence a driver's decision to accept or reject a gap between two successive vehicles of a conflicting traffic stream, are large. These factors can be classified as driver characteristics, and gap attributes. However, most of these studies investigated only time gap acceptance, and few considered one or more contributing factors. The gap acceptance decision process, and the influence of contributing factors are still not well understood.

1.2 RESEARCH OBJECTIVE

The main objective of the research was to enhance the understanding of the driver's gap acceptance decision. The system approach applied in this research is illustrated in Figure 1.2. The research aimed to identify and analyze factors influencing that decision. The study also attempted to determine the relative importance of these factors and the degree of influence that these factors have on a driver's decision. In order to gain the understanding of driver behaviour, a general behavioral model had to be developed to determine the probability of acceptance of a gap of specific size given the system attributes and driver characteristics. The research hypothesis was structured as a set of candidate factors (driver characteristics and gap attributes) that influence a gap acceptance decision.

1.3 RESEARCH FRAMEWORK

The discrete choice theory, which is based on the principle of utility maximization, proved to be a practical tool for the analysis of other travel behavior situations, such as the choice of trip frequencies, destinations, modes, routes of travel and parking locations. In this study, gap acceptance was also considered as a choice situation; i.e., the choice to accept or reject an available gap. There are two possible paradigms for looking at the gap acceptance problem. The first possible paradigm, which was chosen in this research, focuses on each gap as the basic unit of observations, as in the classical gap acceptance studies. For a certain available gap, a driver must decide whether to accept or reject that gap. The approach used is modelling the choice from a set of alternatives using the principle of utility maximization. The driver is assumed to accept a gap if the utility of accepting that gap is higher than the utility of rejecting it. The utility depends on factors classified as driver characteristics and gap attributes.

A second possible paradigm for looking at the same problem is to consider each driver, not each gap, as the basic unit of observations. In this case multiple observations of gap acceptance could be obtained for each individual driver, with only one situation being included. This paradigm was not selected, because the results would not be comparable with the results of the previous gap acceptance research which examined the acceptance / rejection of each available gap as explained in Chapter 5. The results of the chosen paradigm may be different from the results of the second paradigm, which could be investigated in future research.

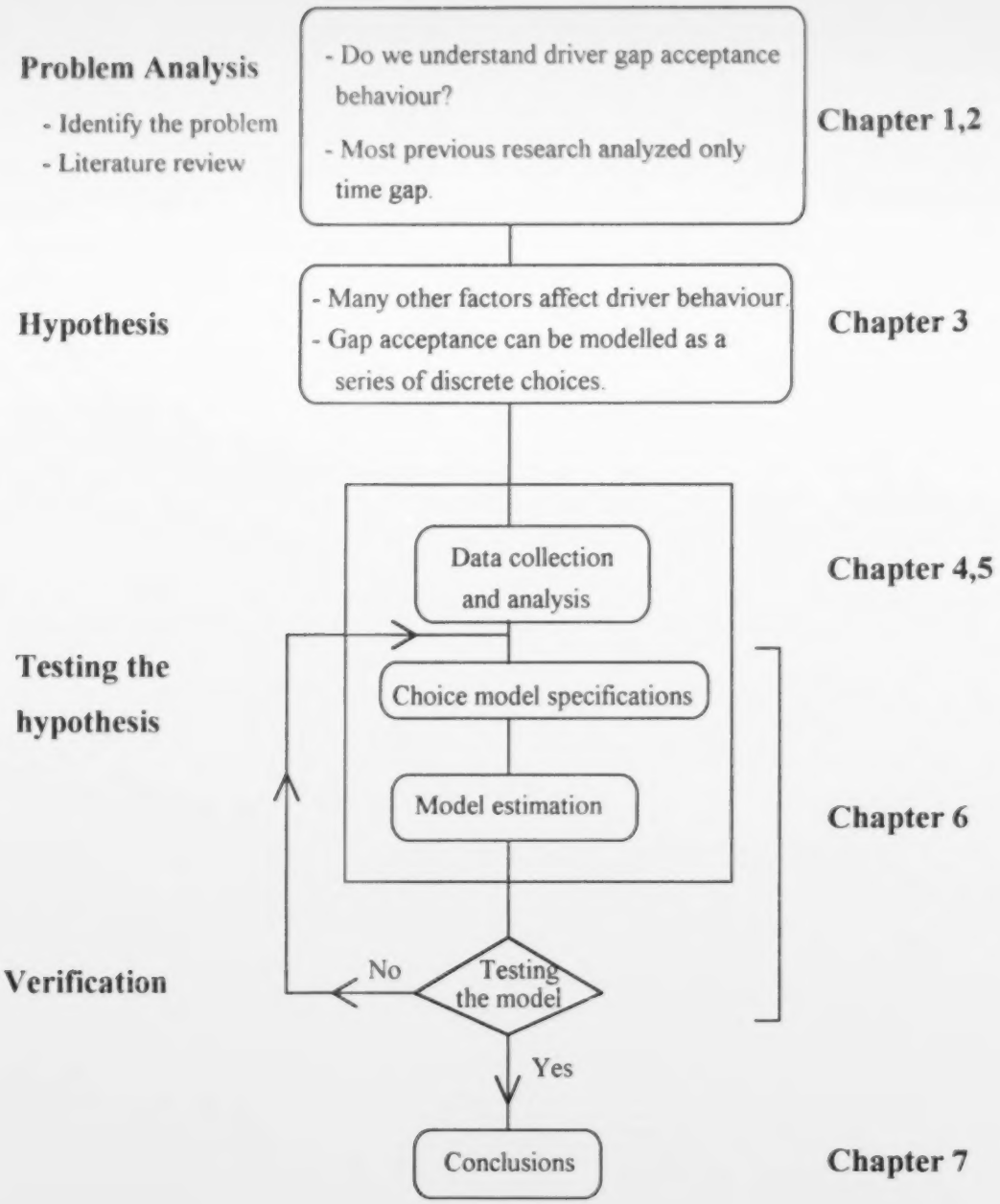

Figure 1.2 System Approach Applied in This Research

The logit model form used in this research is widely used in modelling individual choice behaviour (McFadden et al. 1977). The form of the logit model is relatively simple to calibrate and a large number of variables can be included and analyzed. Computer programs that estimate parameters of the logit model are also available. These reasons make the logit model very attractive for use in this research.

1.4 SCOPE AND LIMITATIONS OF THE RESEARCH

Since the focus of this research was on the understanding of driver behaviour, it was decided to limit the study to a basic gap acceptance situation. The basic situation, which was chosen for this research, is the left turn movement from a major street into a minor street at unsignalized T-intersections (movement 5 in Figure 1.1), which is the simplest type of manoeuver.

Although many factors that might affect the driver gap acceptance decision could have been included in the research, only major factors were considered in this research. These factors are classified into the following categories:

1- Factors related to raffic such as gap size, delay, opposing traffic flow, presence of vehicle behind, speed and type of opposing vehicle
2- Factors related to the driver and the turning vehicle such as driver gender, age, presence of passengers in the turning vehicle, and acceleration capability of turning vehicle,
3- Factors related to geometry of the intersection such as number of opposing lanes to be crossed and their width.

Other factors that might affect driver behaviour were not considered in this research because either they were non observable or they would add undesirable complexity to the problem. These factors can be classified into the following categories:

1- Factors related to traffic such as the influence of the left turns from the minor street into the major street, influence of the right turn from the major street into the minor street and pedestrian activity,

2- Factors related to the driver and the turning vehicle such as psychological, physiological, and socio-economic factors, type of passengers in the car, and in-vehicle environment,
3- Factors related to geometry of the intersection such as sight distance, type of side street, type of control on the minor street (stop sign and yield sign) and shared use of lane,
4- Others such as purpose and length of the trip, weather, pavement, and light conditions.

Data were collected only during off-peak hours and afternoon peak hours, for ideal weather conditions, dry pavement, unrestricted sight distance, and exclusive left turning lanes. Locations with very low pedestrian activity were selected for the study.

1.5 ORGANIZATION OF THE DISSERTATION

Chapter 2 reviews the previous work regarding major gap acceptance investigation methods, and lists factors mentioned in the literature to affect driver gap acceptance behaviour.

Chapter 3 describes the method used in this research and the criteria for model specification. Estimation and calibration techniques are also described.

Chapter 4 identifies data required in this research for model estimation and describes the selected study locations. It also includes an explanation of the procedures used for data collection and entry.

Chapter 5 describes the procedures used for determining the required variables for model estimation from the collected raw data. The chapter also presents an analysis of the collected data, such as the characteristics of the surveyed drivers, gap attributes, and gap situations involved.

Chapter 6 describes the development of a series of discrete choice models. The models and their results are compared, analyzed and discussed. Special issues and the most important findings are presented in detail.

Chapter 7 summarizes the main findings, presents the conclusions of the research, and provides recommendations for future research.

Appendix A briefly describes other research relevant to this study such as traffic safety and time perception, as well as related research at the University of Alberta. Appendix B includes figures supplementary to Chapter 4. A listing of the program used for calculation of the variables required by the logit estimation program is provided in Appendix C. Appendix D includes results of the statistical tests supplementary to Chapter 6.

1.6 TERMINOLOGY

The following section describes terms used specifically in this research project in alphabetical order.

Acceleration capability of turning vehicle: Since the exact acceleration capability of each left turning vehicle would be difficult to measure, it was decided to classify vehicles into three categories. These categories are High, Average, and Low acceleration capability. This classification depends on how long (time) it takes the vehicle to accelerate from 0 to 60 mph (96 km/h). The results of road tests conducted by the Car and Driver magazine (Car and Driver 1984 - 1992) on most types and models of vehicles were used for this classification. The categories were chosen as follows:

Acceleration Category:	Time taken to accelerate from 0-60 mph (96 km/h)
High acceleration capability	< 7.5 s
Average acceleration capability	7.5 - 10.0 s
Low acceleration capability	> 10.0 s

The high acceleration capability category includes mainly sport cars and high powered luxury cars. The low acceleration capability category includes mainly small economy cars and vans. Other types are included in the average acceleration capability

category. The classification has been done for individual cars based on model, approximate age, and condition of the vehicle.

Age of driver: Drivers have been divided into the following three age groups:

1. Young drivers: approximately under 25 years old or clearly young,
2. Middle age drivers: approximately between 25 and 55 years old.
3. Old drivers: approximately over 55 years old.

Drivers who could not be identified clearly as young or old were considered as middle age.

Approach width (Width) : Width of the opposing approach that has to be crossed by the left turning vehicle, measured in metres.

Conflict point: Approximately the center of the conflict area (conflict area of movement 5 with movement 1 in Figure 1.1). Conflict area is a fuzzy term because each vehicle has a somewhat different left turning path.

Front delay (Fdelay): Time elapsed since the minor stream vehicle became the first vehicle in queue and the arrival c^f the front of the major stream vehicle, starting a gap at the conflict point, measured in seconds. The front delay increases in increments of gap size for each successive gap presented to the driver.

Lag: Time elapsed since a left turning vehicle became the first vehicle in the queue, until the arrival of the front of the first major stream vehicle at the conflict point.

Maximum Likelihood (ML) *Method*: A standard statistical technique that is used for estimating parameters of models. It finds the values of the parameters that maximize the likelihood, or for practical reasons, that maximize the log likelihood. The ML method has been used in this research to estimate parameters of gap acceptance models.

Microscopic flow rate (Flow): Major stream traffic flow rate as seen by the driver of the left turning vehicle while waiting for a gap (Kyte et al., 1991).

$$q = N/T$$

where q is the microscopic flow rate expressed as vehicles per minute,

T is the time between the arrival of the left turning vehicle at the head of the queue and the arrival of the through vehicle that ends the accepted gap,

N is the number of through vehicles passing during the time T.

Number of lanes (#Lanes): Number of lanes in the opposing approach that has to be crossed by the turning vehicle.

Number of rejected gaps(#Rej): Number of gaps rejected since the minor stream vehicle becomes the first vehicle in queue, and the arrival of the front of the major stream vehicle starting a gap at the conflict point. The number of rejected gaps increases in increments of one for each successive gap presented to and rejected by the driver.

Presence of passengers (Pass): Presence of passengers in the turning vehicle coded as "1", if there is one or more passenger and as "0", if there are no passengers.

Presence of vehicle behind (Veh.Beh): Presence of vehicles behind the turning vehicle coded as "1", if there is one or more vehicle and as "0", if there are no vehicles.

Queue delay (Qdelay): Time elapsed since a left-turning vehicle joins the queue until it becomes the first vehicle in the queue waiting for a gap, measured in seconds. In this research, the time when a left-turning vehicle joins the queue is considered to be when the vehicle reaches walking speed, approximately 5 km/h. The time when the left-turning vehicle becomes the first vehicle in the queue is considered to be when the front of previous first vehicle passes the conflict point.

Space gap (Sgap): Distance between the front of a major stream vehicle and the front of the following vehicle, measured in metres.

Speed of main stream vehicle (Speed): Time it takes the vehicle to travel between the two points on the major street, divided by the distance between these two points that range from 25 metres to 65 metres in this research.

Time gap (Tgap): Time between the arrival of the front of each consecutive major stream vehicle at the conflict point, measured in seconds.

Type of major stream conflicting vehicle: Vehicle types were divided into five categories as follows:

1. Passenger cars (TypeP): Private passenger cars, vans, pick-up trucks
2. Trucks (TypeT): Single unit trucks, semi-trailer trucks, and motor homes
3. Buses(TypeB): Edmonton Transit buses, school buses, and intercity buses

Trucks (TypeT) and Buses (Type B) were combined as one type in this research (TypeT/B).

4. Motorcycles (TypeM)
5. Bicycles (TypeBI)

Utility (U): Subjective value that reflects the attractiveness of an alternative in terms of its attributes.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

There are numerous empirical and theoretical studies that deal with the gap acceptance phenomena and other related topics. The first section of this chapter gives an overview of the methods that have been used to study driver gap acceptance decisions at unsignalized intersections, and other methods that have been used in related studies and can be used in a study of gap acceptance. The second section summarizes the factors that have been found to affect a driver's decision. The third section lists different methods that have been used to collect gap acceptance data. The fourth section mentions other previous related research and the fifth section provides a summary of the chapter.

2.1 MAJOR GAP ACCEPTANCE INVESTIGATION METHODS

Different methods have been employed in previous gap acceptance studies. Early studies were concerned with the determination of a driver's critical gap. These studies assumed a fixed critical gap for each driver, varying over the population of drivers. Other studies aimed at fitting mathematical distributions to the available gap (headway) and the probability of gap acceptance. Several researchers applied choice theory using the utility maximization principle to obtain the probability of gap acceptance as a function of time gap only.

Review of previous literature indicated that one study applied a fuzzy set theory to study the driver's decision to clear or stop during a signal change interval at a signalized intersection, which is somewhat similar to a gap acceptance decision. Numerical simulation based on various headway and gap acceptance distributions derived from empirical observations, were used to study the probability of accidents at road junctions, and the maximum discharge and average delay to minor stream vehicles. Driving simulator experiments were also used for gap acceptance studies with the focus on an individual's choice rather than on the gap itself. The following sections present an overview of these methods.

2.1.1 Critical Gap Method

The concept of critical gap was first formulated in studies in the 1940's to model gap acceptance situations. It was assumed that each driver has a "critical gap" and would accept a gap in the traffic stream if it is longer than this critical gap. Critical gap was defined by Greenshields in 1947 as the gap that is accepted by 50 percent of drivers, and was defined by Raff in 1950 (as reported by Solberg and Oppenlander 1966 and by many others) as the gap size at which the number of accepted gaps shorter than that particular gap, is equal to the number of rejected gaps longer than that gap. Raff determined the critical gap by plotting two cumulative distributions on the same graph. One curve describes the accepted number of gaps shorter than a time interval, and the other curve shows the rejected number of gaps longer than this interval. The value of the critical gap was determined as the time at which the two curves intersect as shown in Figure 2.1.

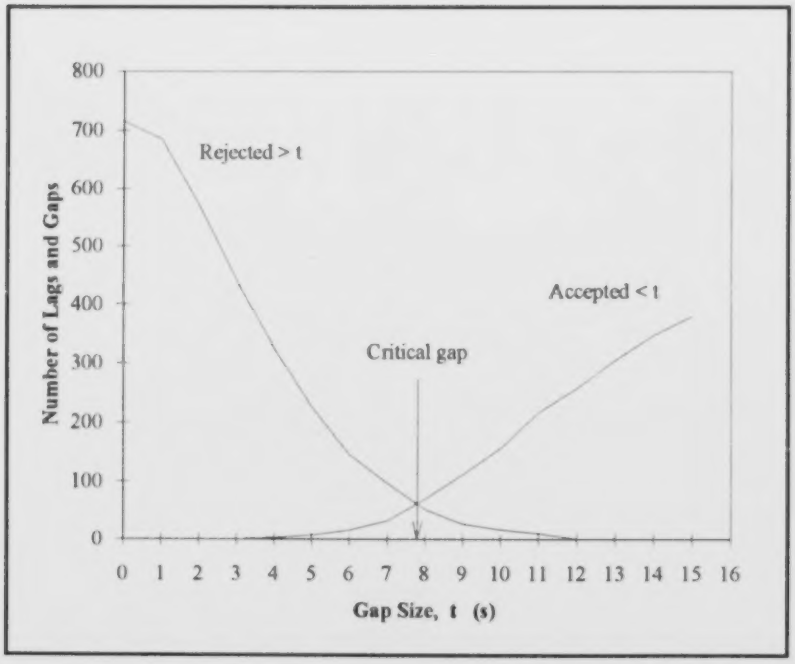

Figure 2.1 Distribution of Accepted and Rejected Lags and Gaps at Intersection Left Turns (Adapted from Solberg and Oppenlander 1966)

Ashworth (1968, 1970) indicated that the gap acceptance curve that shows the percentage of acceptance of various gap sizes, does not indicate the distribution of critical gaps. Ashworth demonstrated that the distribution function for a critical gap can be obtained by displacing the gap acceptance curve obtained from road observation by an amount, depending on major road traffic volume. If major road traffic is randomly distributed and driver gap acceptance curve is normally distributed, the displacement is equal to S^2q , where q is the major road volume (veh/s) and S is the standard deviation of driver gap acceptance curve.

Several probability functions have been used to describe the distribution of critical gap. Drew (1967) fitted a gamma distribution (Pearson Type III) to the distribution of critical gap. Drew considered only drivers who rejected at least one gap before accepting a gap. He assumed that a driver, who accepts a certain size of gap can be expected to accept any gap greater than this size and that a driver who rejected a given gap size can be expected to reject all gaps of a shorter length. A driver's critical gap must lie somewhere in the range between the largest gap rejected and the gap finally accepted. The function form of gamma distribution was described by Drew (1967).

Blunden et al. (1962) estimated the distribution of critical gap by finding the proportion of drivers who accept a certain gap size and the proportion who accept a slightly longer gap. The difference in these proportions gives an estimate of the proportion of drivers whose critical gap is the slightly longer gap. Blunden found that the observed data follow an Erlang form with K= 6 and 7 respectively. Prevedouros (1988) modeled the probability of gap acceptance (probability that a gap equal to or longer than critical gap exists) at an intersection of a single lane major street with a single lane minor street using Erlang-3 distribution, "K=3".

Mahmassani and Sheffi (1981) mentioned that an exponential distribution was used to model drivers' critical gap by Herman and Weiss in 1961.

The Highway Capacity Manual (HCM 1985) procedures for the capacity analysis of unsignalized intersections are based on a German method originally published in 1972 (FGSV 1972). The German method was modified based on a few studies done in the United States. The HCM procedures calculate the capacity at unsignalized intersections, based on the use of gaps in a major traffic stream by vehicles crossing or turning through that stream. Capacity calculation for any movement depends on critical gap size,

conflicting traffic volume, and impedance factor (impedance to a low-priority movement due to utilization of gap by a higher-priority movement). HCM 1985 procedures use the same concept of critical gap, however, its meaning is different than that used in previous studies. The critical gap size is defined in 1985 HCM as "the median time headway between two successive vehicles in the major street traffic stream that is accepted by drivers in a subjected movement that must cross and/or merge with the major street flow". The HCM 1985 stated that the critical gap size depends on a number of factors, including:

- type of manoeuver being executed,
- type of minor street control (stop or yield),
- average running speed on the major street,
- number of lanes on the major street,
- geometric and environmental conditions at the intersection.

Depending on the type of movement made, a basic critical gap size is given based on type of control and major street speed as shown in Table 2.1. Table 2.1 also gives the adjustment to the critical gap size for a variety of conditions.

The unsignalized intersection section (Chapter 10) of the HCM has recently been revised (HCM 1993). The critical gap is defined as "the minimum length time interval that allows intersection entry to one minor stream vehicle". The new gap acceptance method employed by the HCM procedures calculate the potential capacity of each minor traffic stream using the following formula:

$$C_{p,i} = \frac{3600}{t_m} e^{-\frac{t_0 [\sum_j V_{c,j}]}{3600}}$$

where $C_{p,i}$ = potential capacity of minor movement i, in pcph
$V_{c,j}$ = volume of traffic in conflicting stream j, in vph
$t_0 = t_g - [t_m/2]$
t_g = critical acceptance gap, in seconds
t_m = move-up time, in seconds

Table 2.1 Critical Gap Criteria for Unsignalized Intersections (Adapted from HCM 1985)

Basic Critical gap for Passenger Cars (s)					
Vehicle Manoeuver	Type of Control	Average Running Speed, Major Road 30 MPH		55 MPH	
		Number of lanes on Major Road 2	4	2	4
RT from minor road	Stop	5.5	5.5	6.5	6.5
	Yield	5.0	5.0	5.5	5.5
LT from Major Road		5.0	5.5	5.5	6.0
Cross major road	Stop	6.0	6.5	7.5	8.0
	Yield	5.5	6.0	6.5	7.0
LT from minor road	Stop	6.5	7.0	8.0	8.5
	Yield	6.0	6.5	7.0	7.5

Adjustments and Modifications to Critical Gap (s)

Condition		Adjustment
RT from Minor Street	Curb radius > 50 ft or Turn angle <60°	- 0.5
RT from Minor Street	Acceleration lane provided	- 1.0
All movements	Population ≥ 250,000	- 0.5
restricted sight distance		up to + 1.0

From the previous review of the critical gap methods, the following are the definitions of the critical gap that were found to be in use:

1- Critical gap was referred to by Greenshields in 1947 as "the acceptable average minimum time gap" and was defined as the gap that is accepted by 50 percent of the drivers in that gap category.

(e.g. if a 4 second gap is accepted by 30% of drivers and rejected by 70% ,
a 5 second gap is accepted by 50% of drivers and rejected by 50% ,and
a 6 second gap is accepted by 60% of drivers and rejected by 40%,
then the critical gap would be equal to 5 seconds).

2- Critical gap was defined by Raff in 1950 as the gap size at which the number of accepted gaps shorter than that gap is equal to the number of rejected gaps longer than that gap (as shown in Figure 2.1).

3- Critical gap was defined in the 1985 HCM procedures as the median gap size accepted by drivers in a given situation (the median accepted gap).

4- Critical gap was referred to in the new update of Chapter 10 of HCM (1993) as "the minimum length time interval that allows intersection entry to one minor stream vehicle" and was defined as the minimum gap that would be found acceptable by a driver.

Both Greenshields' and Raff's definitions of critical gap are different, but give crisp value that can be calculated from the observed data, while 1985 and 1993 HCM definitions are open to interpretation.

The 1985 HCM procedures definition of the critical gap has the following problems:

- The method relies only on the information about the accepted gaps and ignores all information about the rejected gaps. If drivers accept very long gaps, (for example 20 seconds) that does not tell if drivers would accept shorter ones or not.

- Including the longer accepted gaps causes the calculated critical gap to be unrealistically high which causes underestimation of the value of the calculated capacity at intersections. This fact is supported by results of field observations at various locations in the United States (Transportation Research Circular 373, 1991) which indicated the use of the 1985 Highway Capacity Manual technique yields conservative results.

- The critical gap does not vary according to volume on the major street or the conflict type, although it has been proved these factors affect the size of the accepted gaps (Wagner, 1966 and Kyte et al., 1991).

- The critical gap remains constant over time although it has been proved that drivers will accept shorter gaps as their delay increases (Ashworth and Bottom, 1977, and Kittelson and Vandehey, 1991). This problem is the same for all definitions.

The 1993 HCM new definition of the critical gap has the following problems:

- Critical gap varies only according to type of movement and speed of the major street.

- Critical gap according to this definition is impossible to measure from field observations. It was stated in "NCHRP 3-46 Report" (1993) that critical gap estimation methods is one of the issues that needs to be considered in order to develop capacity analysis procedures for two-way stop-controlled intersections.

- A particular driver would accept any gaps greater than or equal to this critical gap and would reject any gaps less than this value (same as other definitions). These definitions assume that drivers always behave consistently and the value of the critical gap would not be affected by their delay times or by major street volume.

Regardless of the type of the definition of the critical gap, there is an agreement among researchers that the critical gap is impossible to be measured from direct field observations. The only information that can be obtained from field observations is that driver's critical gap is between the largest rejected gap and the accepted gap. This might not be true if drivers accepted gaps shorter than those they previously rejected.

These problems had some influence on the choice of the research method. Discrete choice model does not rely on any of the above definitions. Nevertheless, the gap that has 50 percent probability of acceptance can be calculated from the final models. This value could be compared to the values used in HCM and to the values calculated from the observed data according to both Greenshields' and Raff's definitions.

2.1.2 Available Gaps (Headway) Distribution Method

This method requires the knowledge of the frequency of available gaps (headway distribution) that are greater than or equal to the critical gap. Different distributions have been found to be useful for describing traffic gap (headway).

Buckley (1962) found that generalized Pearson type III distribution, resulted in an acceptable fit. The probability density function of the type III distribution can be stated as follows:

$$P(t) = \frac{1}{\beta \Gamma(k)} \left[\frac{t-a}{\beta}\right]^{k-1} e^{(t-a)/\beta}$$

Where P(t) is the probability density function of headway (t),
a and ß are location and scale parameters,
k is a parameter that determines shape of distribution.

A typical Pearson type III distribution curve is shown in Figure 2.2.

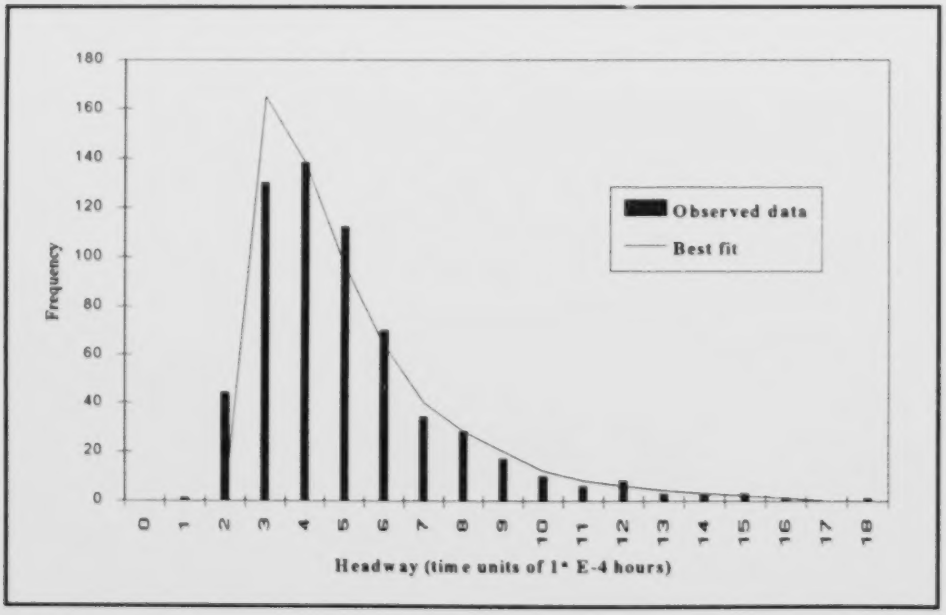

Figure 2.2 Pearson type III (Adapted from Buckley, D. J. 1962)

When k=1 the resulting distribution is a negative exponential (Erlang-1) distribution that fits well only if the arrival of vehicles on the major street is completely random. The probability that a gap (headway) is greater than or equal to a "t" may be written as follows:

$$p(h \geq t) = e^{-t/T}$$

and the probability that a gap is less than "t":

$$p(h < t) = 1 - e^{-t/T}$$

Where T = mean gap (headway) = 3600/V
V = hourly volume.

The shifted exponential distribution is an exponential distribution shifted to the right to take into account a certain minimum allowable headway. Tolle (1976) showed that the composite exponential distribution (composite of shifted and unshifted exponential distribution) is more representative at low traffic volume while Pearson type III is more representative at higher volumes.

When K (in the generalized Pearson type III) is an integer value (>1), the resulting distribution is an Erlang distribution. If K is permitted to be non-integral, the resulting distribution is called the gamma distribution.

Several researchers suggested the use of the log-normal distribution for headway, specially for traffic in platoons.

Dawson and Chimini (1968) proposed the hyperlang probability distribution as a generalized headway model for single-lane traffic flows on two-lane, two-way roadways. The hyperlang model is a combination of the shifted exponential function and the Erlang function. They concluded that the hyperlang distribution is a good representation of the headway for volume ranging from 150 vph to 1050 vph. The Hyperlang distribution, calibrated to German conditions, is also used to generate vehicles into a microscopic, event-oriented simulation program "KNOSIMO" (Chan and Teply, 1991).

2.1.3 Fitting Known Mathematical Distribution to Gap Acceptance Data

This section describes studies that have been made on the distribution of the gaps accepted by drivers turning into and/or crossing a main traffic stream.

Bissel in 1960 as reported by Solberg and Oppenlander (1966) fitted a straight line to data plotted on log-normal probability paper. Wagner (1966) also indicated that the log-normal distribution constitutes a good representation of both accepted and rejected gaps.

The technique of the probit transformation as described by Finney (1971) has been used in a number of gap acceptance studies. The technique is based on the assumption that the logarithm of acceptance time is normally distributed. When the proportion of drivers (p) accepting particular time intervals is converted to probit, a linear relationship exists between the probit of the proportion and the logarithm of acceptance time as shown in Figure 2.3. The linear relationship can be stated as follows (Solberg and Oppenlander, 1966):

$$Y = 5.0 + \frac{1}{\sigma}(X - u)$$

Where Y = probit of the proportion accepting time gap,
X = logarithm of time gap = log t,
u = mean of the tolerance distribution,
σ = standard deviation of tolerance distribution.("where tolerance level is defined as the minimum time gap a driver accepts "

A value of five is added in the equation to ensure the probits are always positive. By using the study data, the mean and standard deviation of the tolerance (minimum acceptable time gap) distribution can be determined. The median gap and lag acceptance times were estimated as the antilogarithm of X when Y= 5.0.

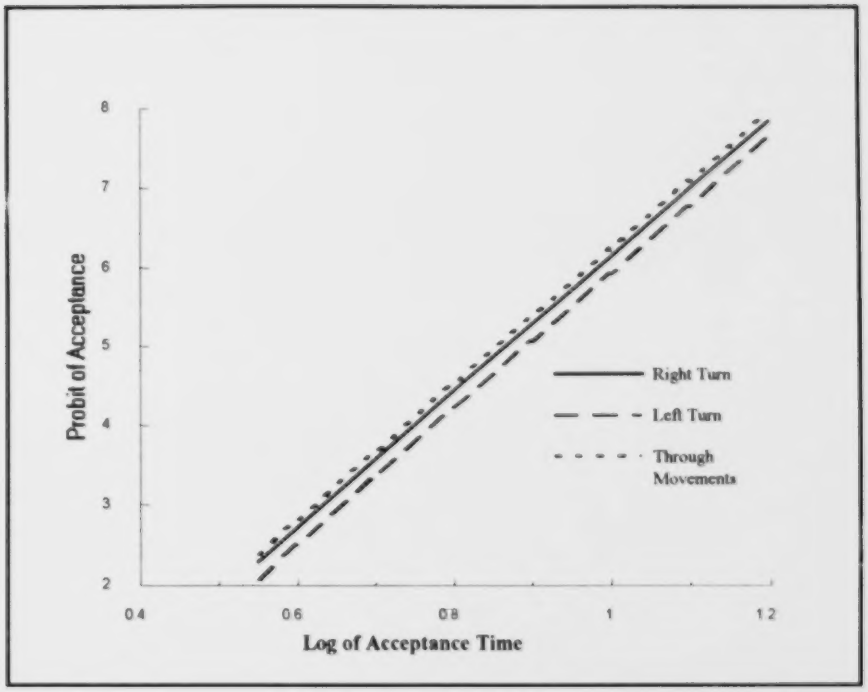

Figure 2.3 Probit Regression Lines for Estimating the Difference in Acceptance Time for Various Movements (Adapted from Solberg and Oppenlander 1966)

Solberg and Oppenlander (1966) used probit transformation technique to investigate the significance of the differences in median lag and gap acceptance times between different movements and between different community sizes. It was found that:

- there was no significant difference between the median lag acceptance and median gap acceptance times.
- the overall median acceptance times for right turn, left turn, and through movement were 7.36, 7.82, and 7.18 seconds respectively.
- the size of the community has some effect on driver acceptance of time gaps. The median acceptance time increased with decreasing city size.

Wennell and Cooper (1981) used the probit transformation technique to determine the median acceptable gap from the original data, then tested the effect of class of the turning vehicle, gender of driver, and presence of passengers on the size of the median accepted gaps. Uber and Hoffman (1988) and Lassarre et al. (1991) also used the probit

transformation technique to determine the median acceptable gap (critical gap) then tested the effect of external factors on the size of the critical gap.

Radwan and Sinha (1980) developed a gap acceptance distribution for all possible manoeuvers, including left turn from a major street into a minor street at the intersection of a four-lane divided highway with a two-lane rural road. They plotted the percentage of gap accepted versus the gap size, and found that the observed data did fit a logistic "S" type curve similar to the probability function employed in the logit model.

2.1.4 Choice Based Models

Probit Model

Daganzo (1981) used the multinomial probit model as a theoretical framework to describe a choice-based gap acceptance process, and used the maximum likelihood approach to estimate the parameters of gap acceptance function (mean and variance of the critical gap). Daganzo stated that although the probit model provided a natural theory framework for the estimation of these parameters, the model seems not to be statistically estimable for this particular problem. Horowitz (1982b), reviewing Daganzo's work (1981), showed that, subject to certain reasonable assumptions concerning the true parameters' values and the probability distribution of gap duration, the maximum likelihood method does yield a consistent estimate of the parameters of Daganzo's model.

Sheffi and Mahmassani (1981) studied driver behaviour when faced with an amber indication using the probit model. This situation was viewed as a binary choice process where the decision is either to stop or proceed through the intersection. Review of this research is provided in Appendix A.

Mahmassani and Sheffi (1981) viewed the gap acceptance process as a series of binary decisions. The first gap longer than the critical gap is accepted. The length of the critical gap for a randomly chosen driver is a function of the number of gaps rejected up to the gap under consideration:

$$T_{cr(i)} = \overline{T}_{cr} + \beta(i-1)^{\delta} + \varepsilon_i$$

Where $T_{cr}(i)$ is the critical gap of a randomly chosen driver when facing the i-th gap in a sequence, $\overline{T}_{cr}$ is the mean critical gap when facing the first gap, β and δ are parameters to be estimated and ε_i is a disturbance term that varies across driver and gaps; ε_i is assumed to be normally distributed.

The probability that a certain driver would accept a given gap of duration 't_i' is given by the probit function:

$$Pr = Pr\,[t_i \geq T_{cr}(i)]$$

$$= \Phi\left(\frac{t_i - \overline{T}_{cr} - \beta(i-1)^{\delta}}{\sigma}\right)$$

Where $\Phi(.)$ denotes the standard cumulative normal curve.

The maximum likelihood estimation technique was used for model estimation. Several model specifications of the gap acceptance function were tried:

1) critical gap depends on the gap's sequential number; i.e. $f(i-1) = \beta(i-1)^{\delta}$,
2) assuming $\delta = 1$ imposing linearity of T_{cr} in (i-1)
3) assuming the critical gap is influenced by the length of the waiting time rather than the number of gaps up to the one accepted.

Results of model estimations are shown as follows:

Parameter	Model 1	Model 2	Model 3
T_{cr}	7.3	7.2	6.9
(T-statistic)	(0.35)	(0.32)	(0.32)
β	-1.4	-0.94	-0.2
(T-statistic)	(1.18)	(0.17)	(0.05)
δ	0.70		
(T-statistic)	(0.84)		
σ^2	5.2	5.4	6.1
(T-statistic)	(2.28)	(1.0)	(1.14)
Log-Likelihood at zero L(0)	-288	-288	-288
Log-Likelihood at convergence L(β)	-89.6	-89.8	-96.9
Likelihood ratio index	0.69	0.69	0.66

The results of the first model specification showed the critical gap decreases as more gaps are passing by. The results of the second model specification suggested the reduction in critical gap is approximately linear with the number of gaps already rejected. The third model results support that the critical gap decreases as the driver waits for an acceptable gap, but this model does not fit the data as well as the model that used the number of rejected gaps.

Logit Model

Maze (1981) used the logit function to model the distribution of gap acceptance of drivers merging from a stop on a one-way, single-lane street into a one-way, single-lane arterial. The model describes the behavior of drivers when they are confronted with a gap acceptance decision under critical conditions (during congested periods). The input to the decision process was:

1) value of risk the driver places on the probability of collision if he accepts the gap,
2) value of delay time the driver assigns to the waiting time until a suitable gap occurs. This value is modified by the length of time spent in the queue at the intersection and the traffic volume on the major street.

Since this input is difficult to measure, driver perceived values are hypothesized to take the following form:

$$VR_i = H(t_i)$$
$$VT_i * f(Q_i, V_i) = G(t_i, Q_i, V_i)$$

Where VR_i = value assigned to the risk of accepting gap i,
t_i = time length of gap i,
VT_i = value assigned to the time penalty estimated for refusal of gap i,
$f(Q_i, V_i)$ = function that accounts for modifications in driver delay-time judgment
Q_i = queue length in minor stream at time of gap i
V_i = main stream traffic volume at time of gap i.
$H(t_i)$ = function of t_i
$G(t_i, Q_i, V_i)$ = function of t_i, Q_i, and V_i

If the value of risk assigned to accepting a gap is greater than the assigned value of delay due to rejecting a gap; $H(t_i) > G(t_i,Q_i,V_i)$, then the gap is rejected. If the value of risk assigned to accepting a gap is less than the assigned value of delay due to rejecting a gap; $H(t_i) < G(t_i,Q_i,V_i)$, then the gap is accepted.

Since the variable used to model the value of risk , $H(t_i)$, is a subset of the variables used to model value of delay time, then the model can be written as follows:

$$H(t_i) - G(t_i,Q_i,V_i) = F(t_i,Q_i,V_i)$$

The simple logit function that has been used to model the choice is:

$$P = \frac{1}{1+e^{F(x)}} \qquad -\infty < F(x) < \infty$$

and its linear transformation is:

$$\ln[P/(1-P)] = F(x)$$

Where P = cumulative probability of accepting a gap
F(x) = linear function
x = variables related to the gap acceptance decision

By using the logit function, the model was specified as below:

$$P_i = F_L\,(\beta_0 + \beta_1 X_i + \beta_2 Q_i + \beta_3 V_i)$$

Where P_i = cumulative probability of accepting a gap i
$F_L(\,)$ = logit function form
β = coefficients to be estimated,
$X_i = (T/t_i) - 1$
T = mean time length of all gap accepted

By using ordinary least squares, the cumulative probability of accepting a gap of specific length was modeled with a reasonably good fit as follows:

$$Yi = 0.422 - 0.965\,[T/t_i - 1] \qquad R^2 = 0.931$$

Where $Y_i = \ln [P_i/(1-P_i)]$

The results of this model indicated that the volume of main stream traffic and the length of the queue do not seem to affect the length of the gap accepted. These are surprising results since the queue length was sometimes as long as 20 cars.

Fitzpatrick (1991) used the following logit form to determine the gap acceptance values for truck and passenger car drivers:

$$P = \frac{1}{1+\exp[-(\beta_0 + \beta_1 X)]}$$

Where P= probability of accepting a gap,
X= variable related to gap acceptance decision, gap size,
β_0, β_1 are regression coefficients.

The result of plotting the logit model is shown in Figure 2.4.

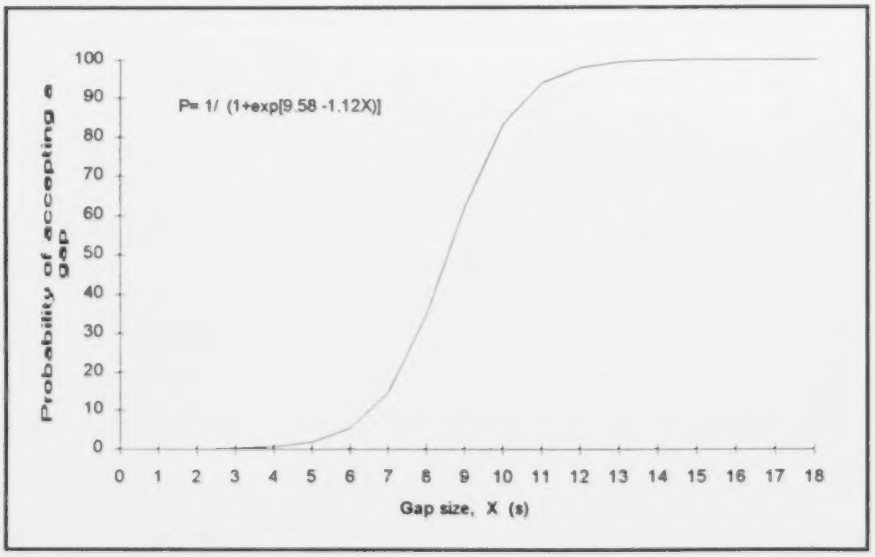

Figure 2.4 Logit Method Plot for Five-Axle Trucks (Adapted from Fitzpatrick 1991)

In a review by Prevedouros (1988) of the research using utility maximization choice modelling to obtain the probability of gap acceptance, he concluded that the resulting models are either highly insignificant (Daganzo 1981, using probit) although correct from a behavioural and mathematical point of view, or extremely simplified (Maze 1981, using logit). Fitzpatrick's model (1991, using logit) is also too simple to reflect the reality adequately.

2.1.5 Other Methods

Kikuchi and Riegner (1991) applied a fuzzy set theory to analyze a driver's decision between "stop" and "clear" during a signal change interval. Information available to a driver concerning location, approach speed, time remaining in the signal change interval, and other parameters is fuzzy. A driver must make the decision based on this fuzzy information. The research concluded that the fuzzy set theory approach, could be used to analyze other similar binary choice situations that involve risk-measurement problems.

Webster and Cobbe (1966), and Salter (1976) described that Tanner in 1962, developed mathematical simulation to estimate the average delay to minor road vehicles and the maximum discharge from the minor road at a priority intersection, based on headway and gap acceptance distribution. Darzentas et al. (1981 c) used a discrete-event simulation model to investigate driver behaviour at a simple priority T-intersection. The research aimed at examining the factors that affect the probability of accidents at road junctions. Drivers' turning decisions in the simulation model are based on gap-acceptance functions which were derived from empirical observations. In the simulation model, a driver wishing to turn is presented with a sequence of time gaps between vehicles on the main road. The decision to accept or reject a gap was made by comparing the presented gap, to a gap sampled from the appropriate distribution of acceptable gaps. The simulation allows for different classes of vehicles with different characteristics. Darzentas et al. (1980 a) employed the same model to examine how the age and gender of the turning driver affect conflict rate at intersections, using gap acceptance functions for samples of male and female drivers in different age ranges.

Ebbesen et al. (1977) used driving simulation laboratory experiments to study the effect of speed and distance of oncoming vehicles on a driver's decision to cross. It was

hypothesized that if a driver judged that the risk of crossing in front of an oncomming car is lower than a specific amount, the individual would choose to cross; otherwise would wait for the car to pass. It was also hypothesized that the perceived risk (R) would be a weighted sum of the perceived speed (v) and the reciprocal of the perceived distance (d) of the oncoming car, as in the following equation:

$$R = a(v)+b\left(\frac{1}{d}\right)+c$$

Where a,b,c are regression parameters.

Hancock et al. (1991) examined drivers' responses in turning left across a line of traffic as presented in a closed-loop, interactive, fixed base driving simulator. Drivers were located near an intersection and instructed to turn left across a stream of on-coming traffic when they felt that it was safe for them to do so.

2.2 FACTORS AFFECTING GAP ACCEPTANCE

Many studies have been conducted to investigate the various factors that may affect the driver's decision to accept or reject a gap at unsignalized intersections. This section discusses the factors that are mentioned in the literature and are listed as follows:

- Driver age
- Driver gender
- Presence of passengers in the turning vehicle
- Delay or number of rejected gaps
- Class of turning vehicle
- Type of opposing vehicle
- Speed of opposing vehicle
- Opposing traffic volume
- Conflict type
- Type of manoeuver
- Type of control
- Level of pedestrian activity
- Time of day
- Others

The following is an overview of the effect of these factors.

2.2.1 Driver Age

Darzentas et al. (1980 a, c) studied the effect of age on the minimum acceptable gap when crossing a single lane of traffic at a T-intersection in a numerical simulation study. The result showed that younger drivers neither accepted shorter gaps nor was their crossing time shorter than older drivers. However, young drivers were more consistent in their driving behaviour than older drivers. This result might be due to the wide range of perception and physical capabilities of older drivers.

2.2.2 Driver Gender

Wennel and Cooper (1981) , using the probit transformation technique, found that the mean accepted gap for women drivers is longer than that for men. The size of the difference varies with site and type of manoeuver. These results confirm those of the study by Ebbesen and Haney as reported by Wennel and Cooper (1981), that also showed that the difference in median values between male and female is almost half a second. The study by Darzentas et al. (1980a, c) showed that females are more cautious than males in assessing the time required to cross a single lane of traffic at T-intersections and females take longer to complete the manoeuver. The result also indicated slightly poorer judgment of speed and less consistency for female drivers than for males.

2.2.3 Presence of Passengers in the Turning Vehicle

Results of a study by Ebbesen and Haney as reported by Wennell and Cooper (1981) indicated that no significant difference was detected in gap acceptance behaviour for vehicles containing passengers if vehicles did not wait at the intersection. However, drivers accepted shorter gaps after being forced to wait at intersections if they did not have passengers, than if they did have passengers. Wennel and Cooper (1981), using the probit transformation technique, found that there are no consistent effects of the presence of passengers on the size of the median accepted gap. Jackson and Gray (1976) studied the effect of passengers' gender on the driver's waiting time for an acceptable gap, from direct road observations. Results showed that male drivers with male passengers had significantly shorter waiting times than either male drivers without passengers or female

drivers with female passengers. Figure 2.5 shows the mean waiting time for male and female drivers with various passenger conditions.

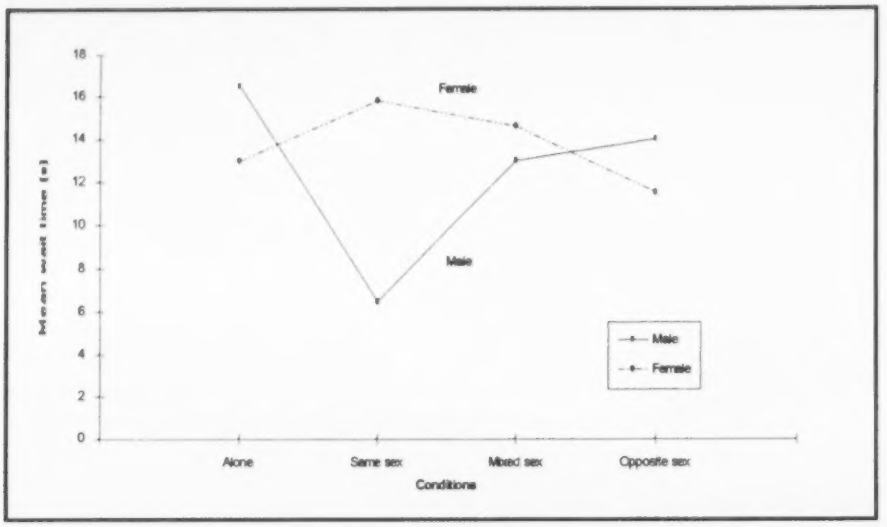

Figure 2.5 Effect of Gender of Passengers on the Mean Waiting Time (Adapted from Jackson and Gray 1976)

2.2.4 Delay or Number of Rejected Gaps

Total delay incurred by the turning or crossing driver has two components:

1- the front-of-queue delay

2- delay time spent in the queue behind other vehicles.

Drew (1967) studied gap acceptance characteristics for merging vehicles at freeway entrances. The critical gap for a stopped vehicle (whose driver rejected gaps before accepting one) was found to be about 20 percent higher than for moving vehicle (whose driver accepted the first gap)

Ashworth and Bottom (1977) found that the longer the waiting time at the head of the queue, the greater the probability of gaps being accepted. 60% of drivers who waited more than 8 seconds accepted gaps shorter than 6 seconds compare to 40% of drivers

who waited less than 8 seconds. This can explain the finding, that gaps were more likely to be accepted than lags of equivalent size, due to the difference in waiting time.

Adebisi and Sama (1989) compared mean critical gaps obtained for different durations of stopped delay with the value from the aggregate data. The average delay for the aggregate data was 19.02 seconds. The results showed that the critical gap for drivers who experienced delay of up to 25 seconds is higher, while the critical gap for those who experienced delays of more than 30 seconds is lower than the value obtained from the aggregate data. This indicates that the drivers exhibit significant changes in their gap acceptance behaviour when the average delay is out of the 25-30 second range. They begin to accept shorter gaps than normal when the delay exceeds 30 seconds. This study was limited to the situation where there is little or no queue build up. The following regression relation was established:

$$c = 18.64 - 0.226\ d \qquad (r^2 = 0.772)$$

Where c is the mean critical gap in seconds,
d is the average delay in seconds.

Kyte et al. (1991) found that mean accepted gap tends to decrease as the queue time (delay time spent in queue behind other vehicles) and/or service time (front-of-queue delay) increase. In this study, the average total delay per vehicles at different intersections ranged from 11 to 25 seconds.

Kittelson and Vandehey (1991) concentrated on only the front-of- queue delay time. They showed a strong negative correlation between the delay incurred by the driver in the front of the queue and the mean critical gap. The observed front delay ranged from 0 to beyond 40 seconds. The researchers indicated that the average front delay was 19.5 seconds for drivers whose accepted gap was shorter than one or more previously rejected gaps, and the average accepted gap was about 3.5 seconds. The average front delay was 8.9 seconds for drivers whose accepted gap was longer than all previously rejected gaps and the average accepted gap was around 6.0 seconds. They also showed a similar strong negative relationship between the number of longer gaps previously rejected and the length of the observed accepted gap.

Mahmassani and Sheffi (1981) found that the driver's critical gap is influenced by the waiting time and by the number of rejected gaps up to the accepted gap. The researchers did not mention the range of delay observed nor the number of rejected gaps. A model using the number of rejected gaps fitted the data better than a model using the delayed time.

$$T_{cr}(i) = T_{cr} + \beta\,(i-1)$$

Where $T_{cr}(i)$ = critical gap for a randomly chosen driver when facing the i-th gap in sequence,

T_{cr} = mean critical gap when facing first gap i=1

$\beta(i-1)$ = function of the rejected gaps up to gap i,

β = parameter to be estimated.

This result suggested that critical gaps decrease during the time drivers are waiting (as more gaps are passing by). The results also suggested that the reduction in the critical gap is approximately linear with the number of gaps already rejected. The result is consistent with findings from other research (Chan and Teply, 1993) which indicated that a significant improvement in accident prediction models can be achieved when delay is used as an independent variable, rather than the usual conflicting flows or their combinations.

There is agreement among researchers that the mean accepted gaps tend to decrease as the delay time increases. The possible inference is that the longer a vehicle waits the greater the driver's frustration, which makes a gap that previously seemed too short, acceptable. Another reason is that the longer the wait, the longer they can observe physical and traffic parameters of the situation and are therefore able to better estimate the size of an acceptable gap. While the first reasoning can be classified as "risk behaviour", the second can be described as a "learning process". It is likely that both are at play here to varying degrees depending on the characteristics of individual drivers.

2.2.5 Class of Turning Vehicle

Blunden et al. (1962) found that the difference in the mean rejected gap between cars and trucks is not as marked as one would expect. The explanation was that longer sight distance for trucks might have a compensating effect where they kept moving without stopping at an intersection.

Wagner (1966) measured the lag and gap acceptance distribution for car and truck drivers, and the results of the testing led to the conclusion there is no evidence that truck driver behaviour and car driver behaviour are significantly different.

Wennel and Cooper (1981) concluded that drivers of trucks waited for longer gaps than drivers of cars. The difference in median accepted gap between cars and trucks is longer for merging manoeuvers than for crossing, due to the difference in acceleration capability, where the vehicle must attain the speed of oncoming major road traffic after a turn. Fitzpatrick (1991) found that the critical gap for truck drivers was 8.5 seconds compared to 6.5 seconds for passenger car drivers. Lassarre et al. (1991) found that drivers of heavy vehicles accept slightly longer gaps than drivers of light vehicles, whatever the type of manoeuver.

2.2.6 Type of Opposing Vehicle

Hancock et al. (1991) found that drivers turning left across a line of traffic rejected more gaps in front of large vehicles than in front of other types. The explanation was, the larger the vehicle, the more threatening it appeared.

2.2.7 Speed of Opposing Vehicle

Cooper et al. (1976) classified accepted and rejected gap data for merging manoeuvers according to the speed of the approaching main road vehicle. Probit analysis was used to estimate the parameters of the distributions. It was found that there is a positive correlation between the median accepted gap and the approach speed, as follows:

$$D = 11.5 + 5\,V \qquad \text{and} \qquad T = 5 + 11.5 / V$$

Where D = median accepted gap distance in metres,
T = median accepted gap time in seconds,
V = speed of main road vehicle in metres per seconds .

Ashworth and Bottom (1977) found that for the same measured gap size (in time), the mean speed of the approaching vehicles that led to accepted gaps is significantly higher than the mean speed of vehicles associated with rejected gaps, (reverse to what might be expected). When calculating the gap size in terms of distance, it was found that the accepted gaps are associated with a lower speed than the rejected gaps. The result of the first case (same time gap) might be explained as, for the same gap size in time, the higher the speed, the higher the distance gap that makes it acceptable to drivers. In the second case, for the same gap size in distance, the longer the time gap, the lower the speed which makes it acceptable to drivers.

Uber and Hoffmann (1988) found that the speed of a vehicle approaching a major road has a significant effect on the gap acceptance decision, but has no significant effect on the lag acceptance decision of drivers who have been delayed in a traffic queue. This finding can be shown as follows:

For gaps $T = 7.26 - 0.11\ V$ $r^2 = 0.609$
For lags $T = 5.50 - 0.0042\ V$ $r^2 = 0.005$

Where T is the mean critical interval in seconds,
V is the approach speed in m/s.

There appears to be little agreement among researchers on the correct model to relate approach speed to the accepted gap or lag size. However, there is support for the existence of some effect of the approach speed on the gap acceptance by minor road drivers.

2.2.8 Opposing Traffic Volume

Wagner (1966) indicated that the pressure of traffic demand is one of the factors that has the most effect on the lag and gap acceptance. Drivers accept smaller gaps and lags during peak periods than what they will accept during off peak periods. It was found

there was more than a two second difference between the median acceptable lag during peak and off peak periods. In the case of gap acceptance the difference is not significant.

Polus (1983), and Kyte et al. (1991) found that the size of the accepted gap decreased as the major street flow rate increased. Polus found that the average accepted gap was 9.59 seconds at a location with a 240 veh/h major-street flow rate, compared to 8.51 seconds at another location with a 305 veh/h flow rate. Kyte et al. found that the average accepted gap was 12.0 seconds when the flow rate on the major street was less than 300 veh/h and ranged between 5.6 to 7.7 seconds at a different intersection with a major street flow rate greater than 900 veh/h.

Fitzpatrick (1991) found that for both right and left turning manoeuvers, passenger car drivers had an 85 percent probability of accepting a gap of 8.25 seconds at a moderate- to high-volume intersection and 10.5 seconds gap at a low volume intersection. Lassarre et al. (1991) observed that drivers adapt their behaviour to the type of traffic and accept shorter gaps when traffic is very dense than when volume is low. A possible inference is that as the major street flow rate increases, the size of the available gaps becomes smaller, therefore, drivers tend to cross or merge more aggressively and accept what is available in order to minimize their delay.

2.2.9 Conflict Type

Kittelson and Vandehey (1991) concluded that drivers evaluate the acceptability of a gap on the amount of time they expect to be exposed to a major street conflict. Thus a driver turning left from a minor street will require a longer gap between conflicting vehicles approaching from the right, than between vehicles approaching from the left.

2.2.10 Type of Manoeuver

Blunden et al. (1962) and Kyte et al. (1991) found that the size of the required gap for a through vehicle is smaller than that for a turning vehicle because the through vehicle must only clear the intersection, while the turning vehicle must also merge into the conflicting vehicle stream.

Radwan and Sinha (1980) compared distribution for all possible manoeuvers at the intersection of a four-lane divided highway with a two-lane rural road. They found that the

average gap required for a right turn manoeuver (6.73 s) is not significantly different from the average gap required for a left turns made from the median (6.60 s). They also found that the average gap acceptance for drivers who turned left without stopping at the median (6.32 s) was less than the average gap for drivers who turned after stopping at the median (6.60 s). Furthermore, the average gap acceptance value for drivers who turned left without stopping at the median was found to be less than the average gap acceptance value for drivers who crossed the major road after stopping at the median. These findings were explained as drivers who perform their movements in one manoeuver are more aggressive.

2.2.11 Type of Control

Polus (1983) found that the accepted and rejected gap sizes at a stop sign approach were longer than those at a yield sign approach. The reason is that the stop sign at an intersection forces drivers to come to a complete stop.

2.2.12 Level of Pedestrian Activity

Polus (1983) found with an increasing level of pedestrian activity, the drivers tend to behave more cautiously so that the mean accepted and rejected gaps tend to rise.

2.2.13 Time of Day

Darzentas et al. (1980) found for merging manoeuvers, the median accepted and rejected gaps in darkness are smaller than those in daylight. They conclude that drivers accept smaller gaps at night than in daylight. This result is consistent with accident studies that show a higher accident involvement rate in darkness. In interviews with a sample of drivers, they said they were more cautious in making their decision in darkness. This means they had difficulties in judging the speed and distance of oncoming vehicles at night even in the presence of street lighting, which led to overestimating the time gap available at night. This result seems to contradict the finding from another research by Lassarre et al. (1991) who found that drivers choose longer gaps at night than in the morning. Nevertheless, the researchers stated that the reason might have been in the fact that traffic volume at night is less dense than in the morning. This explanation would be consistent with section 2.2.8.

2.2.14 Other Factors

In addition to previous factors, there are still many other factors mentioned in previous studies that have an effect on driver decision. These include main stream arrival pattern (platoons or randomly), number of lanes on the major street, shared use of lanes, sight distance, presence of vehicles behind the turning vehicle, size of the subsequent gap to the gap under consideration, weather and pavement condition, physical characteristics of the opposing vehicle such as color, size, frontal surface area, and shape. Other factors include acceleration capabilities of the turning vehicle, and length of the arc that must be travelled to complete the turn.

2.2.15 Summary

From the previous review of past work, the factors that might influence a gap acceptance decision can be classified into four major categories, as follows:

1- Factors related to driver: such as age and gender of the driver, presence of passengers, and type of the turning vehicle.

2- Factors related to turning traffic: such as delay or number of rejected gaps, type of the manoeuver, and presence of a vehicle behind.

3- Factors related to opposing traffic: such as gap size between successive vehicles, flow rate, type and speed of opposing vehicle, and presence of pedestrians.

4- Other factors: such as road environment, number of lanes or width to be crossed, time of the day, weather, and pavement condition.

The conclusion from the previous review is that none of these factors alone can explain completely the gap acceptance behaviour of drivers at an intersection. The overall behaviour is influenced by many of these factors together. The models that only use one variable, likely lack a general explanation power and are not suitable for micro analysis applications.

2.3 METHODS OF COLLECTING GAP ACCEPTANCE DATA

Several methods of data collection have been used in the past research. These methods can be grouped into the following categories:

1- Time-lapse photography (time-motion pictures),

2- Events pen recorder actuated either by the observer using a hand operated switch or by road tubes/ cables,

3- Controlled field experiments,

4- Laboratory driving simulation experiments,

5- Closed circuit television or video camera,

6- Lap top computer.

Overview of the procedures used in the previous research for collecting gap acceptance data are presented in Appendix A.

2.4 OTHER PREVIOUS RELATED RESEARCH

Other related research on driver traffic safety behaviour, time perception as well as related previous research at University of Alberta are summarized in Appendix A.

2.5 SUMMARY

Previous studies employed various techniques for studying the gap acceptance phenomena. These studies and practical experience provide background to assemble an initial list of factors that have the potential to influence a driver's decision to accept or reject a gap between two successive vehicles of a conflicting traffic stream. Most of the research investigated only time gap acceptance, and few studied the effect of other contributing factors on gap acceptance. In spite of the great number of past studies on driver gap acceptance decision, our understanding of this problem remains significantly incomplete.

The number of factors mentioned in the literature is large, therefore it was important that the studied conflict situation be as simple as possible, and that a careful selection of influencing variables would be necessary. Moreover, a suitable analytical method capable of handling a large number of variables was needed.

It was decided that this study would focus only on left turning movements from a major street into a minor street at unsignalized T-intersections. This type of movement is the simplest type of manoeuver because drivers have to watch for only one conflicting traffic stream while crossing. It was also decided to use the discrete choice theory as a frame work for this research, because it fit the plan decided for the study of the gap acceptance problem.

CHAPTER 3

RESEARCH METHODOLOGY

3.0 INTRODUCTION

The objective of this research, is to understand driver's gap acceptance decision. The study focuses on the left turning movement from a major street into a minor street at unsignalized T-intersections. The literature review, as described in Chapter 2, indicated that there are a variety of factors that affect this behaviour but most of the research investigated only time gap acceptance. Only some of the literature included one or more contributing factors which can not explain completely the overall behaviour or are not suitable for micro analysis applications.

The plan for this research called for a study of a variety of factors identified in the literature to affect the driver behaviour. Therefore, there was a need for a suitable technique for handling a great number of variables. It was decided to view the problem as a choice situation as described in Section 3.1 of this chapter. In Section 3.2, the principles of the choice theory are reviewed. The model building processes: specification, estimation, and calibration, are described in Sections 3.3, 3.4, and 3.5 of this chapter.

3.1 DESCRIPTION OF THE PROBLEM STUDIED

Since the focus of this research was on the understanding of driver behaviour, it was decided to limit the investigation on left turn movement from a major street across an opposing traffic stream at unsignalized T-intersections. This type of movement is the simplest type of intersection maneuver since drivers have to deal with only one conflicting traffic stream, and their attention is not distracted by other opposing movements, signs or traffic control signals.

The problem can be described as drivers, who intend to turn left and arrive at the head of the queue at position A in Figure 3.1, must perceive the fixed attributes of the geometric layout as well as the continuously changing attributes of the opposing traffic and pedestrians. They assess these stimuli and must decide with each successive vehicle of

the opposing flow whether to wait or proceed. The decision is guided mainly by two motives: (1) to minimize the travel time, and (2) to proceed as safely as possible. As the rate of opposing flow increases these two requirements become increasingly conflicting.

Drivers make their decisions on the basis of what they experience while at the decision-making position (Position A in Figure 3.1) and while considering the immediate attributes of an available gap. The attributes of the following gaps, provided the drivers can see and judge them, may also influence the decision of whether to wait or to proceed.

The above description of the process may lead to two different choice model forms: (1) choice among different available gaps, and (2) choice to accept or reject the current gap. In this study, the decision situation has been interpreted only as a choice to accept or reject the current gap.

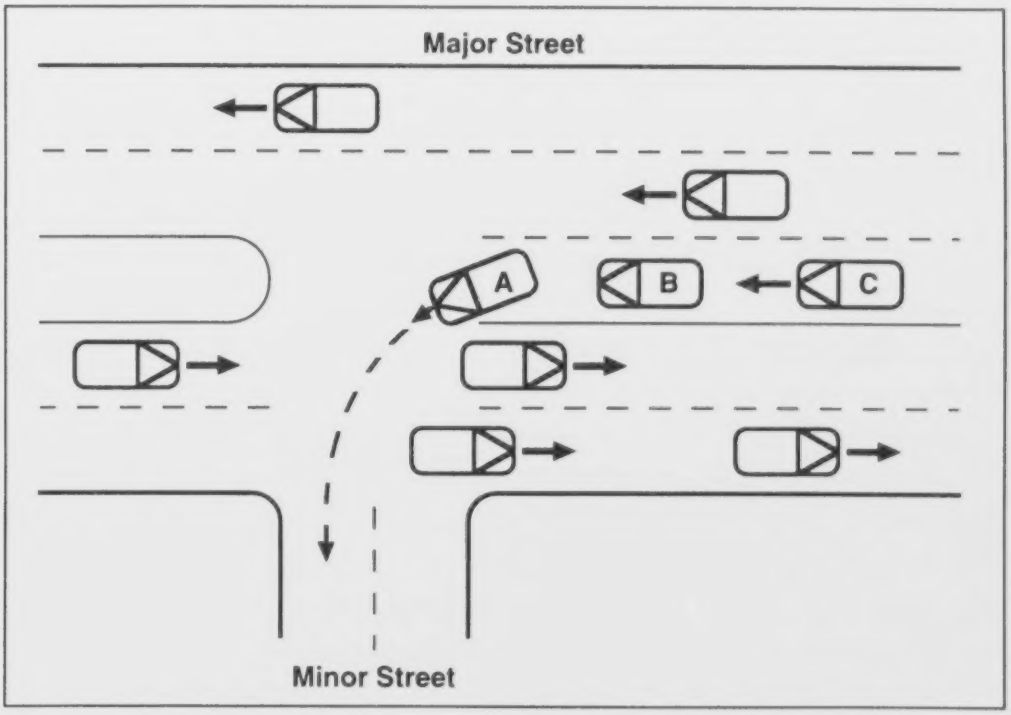

Figure 3.1 Description of the Gap Acceptance Problem

3.2 DISCRETE CHOICE THEORY

Ben-Akiva and Lerman (1985) identified a choice as an outcome of a number of steps that include:

Step 1: Definition of the choice problem,
Step 2: Generation of available alternative choices,
Step 3: Evaluation of attributes of alternatives,
Step 4: Choice,
Step 5: Implementation.

There are two general types of choice sets. In the first type, the choice set is continuous, while in the second type, the choice set is discontinuous (alternatives are discrete). A choice from a set of alternatives requires a decision rule that describes the way the decision maker arrives at a unique choice. There are many decision rules mentioned in the literature such as dominance, elimination by aspect, and utility maximization. The utility maximization concept is widely used in decision making analysis (Ben-Akiva and Lerman, 1985) and was used in this research.

3.2.1 The Principle of Utility Maximization

The principle of utility maximization is that an individual assigns a certain subjective value called "utility" that reflects the attractiveness of choice alternative in terms of its attributes (Ben-Akiva and Lerman, 1985). The decision maker is always assumed to choose the alternative with the highest utility. The utility of an alternative can be presented as a function of the attributes of the alternative, as well as the characteristics of the decision maker.

The utility is not deterministic but is a random variable with a specific distribution. Therefore, the individual choice can better be described as a probabilistic choice from a set of alternatives. The probability of choosing one alternative out of the complete set of alternatives, equals the probability of the utility of that alternative being greater than or

equal to the utilities of all other alternatives. The probability of choosing alternative i is as follows:

$$P(i|C_n) = Pr\,[\, U_{in} \geq U_{jn}\,, \quad \forall\, j \in C_n\,, j \neq i\,]$$

where $P(i|C_n)$ is the probability of choosing alternative i out of a complete set of possible alternatives,
C_n is the set of alternatives available to individual n,
U_{in} is the utility of alternative i to individual n.

Utility can be represented as the sum of two components (Richards and Ben-Akiva 1975):

The deterministic component, denoted as V_{in}, accounts for the effects of the observed characteristics of the alternative and the individual by including variables that characterized alternative i, denoted as Z_{in}, and the variables describing the decision maker, denoted as S_n, therefore, V_{in} can be expressed as follows:

$$V_{in} = V(Z_{in}, S_n) = V(X_{in})$$

where X_{in} is a vector of attributes that include both Z_{in} and S_n.

The random component or disturbances, denoted as E_{in}, accounts for the effects of unobserved characteristics of individuals and alternatives, unobserved taste variation, measurement errors and imperfect information (Ben-Akiva and Lerman 1985).

The utility function therefore can be expressed as follows:
$U_{in} = V_{in} + E_{in}$,

3.2.2 Binary Choice Model

In this research a special case of choice situations was considered in which the driver faces two alternatives: to accept or to reject a gap. Such a situation is termed a binary choice situation. The used approach is modelling the choice from a set of alternatives using the principle of utility maximization. The driver is assumed to select the alternative with the highest utility.

The choice set will be denoted as C_n : {i,j}
where alternative i is to accept certain gap,
alternative j is to reject this gap.

The probability that a person n will choose alternative i is as follows:
$P_n(i) = pr(U_{in} \geq U_{jn})$,

and the probability of choosing alternative j is :
$P_n(j) = 1 - P_n(i)$.

$$\begin{aligned} P_n(i) &= Pr\,(U_{in} \geq U_{jn}) \\ &= Pr\,(V_{in}+E_{in} \geq V_{jn}+E_{jn}) \\ &= Pr\,(E_{jn}-E_{in} \leq V_{in}-V_{jn}) \\ &= Pr\,(E_n \leq V_{in} - V_{jn}) \end{aligned}$$

where $E_n = E_{jn}-E_{in}$,
U_{in}, V_{in}, and E_{in} are as mentioned in previous section.

Varying the assumptions about the distributions of E_n leads to a different mathematical form of the choice models. When E_n is uniformly distributed between two fixed values -L and L, the mathematical form is linear probability model (Ben-Akiva and Lerman, 1985).

$$\begin{aligned} P_n(i) &= 0 && \text{if } Vin - Vjn < -L \\ &= \frac{Vin - Vjn + L}{2L} && \text{for } -L \leq Vin - Vjn \leq L, \\ &= 1 && \text{if } Vin - Vjn > L. \end{aligned}$$

Under the assumption that the term E_n is normally distributed, the mathematical model is called probit (Ben-Akiva and Lerman, 1985). The form of the binary probit is as follows:

$$P_n(i) = \Phi\left(\frac{Vin - Vjn}{\sigma}\right)$$

where $\Phi(\ )$ denote the standardized cumulative normal distribution,
$1/\sigma$ is the scale of the utility function which can be set to an arbitrary positive value.

The logit model arises from the assumption that E_n is logistically distributed (represented by the Weibull distribution).

$$P_n(i) = \frac{e^{V_{in}}}{e^{V_{in}} + e^{V_{jn}}}$$

A convenient assumption is that the function V_{in} is linear in unknown parameters[1] (McFadden, 1974):

$$V_{in} = \beta_1 X_{in1} + \beta_2 X_{in2} + \beta_3 X_{in3} + \ldots\ldots + \beta_k X_{ink}$$

where X_{in} are observed variables describing the attributes of a gap and driver's characteristics and $[\beta_1, \beta_2, \beta_3, \ldots\ldots, \beta_k]$ is a vector of k unknown parameters to be estimated.

The variables X_{in} can be either generic or alternative specific variables.

Generic Variable: if the variable X_{ink} appears in the utility functions of all alternatives, it is termed a generic variable.

Alternative Specific Variable: if the variable X_{ink} appears only in the utility function of alternative i, and takes a value of zero for all other alternatives, the variable is termed as alternative specific variable. For J alternatives, there can only be (J-1) alternative specific constants.

Although the probit model might be considered to be superior to the logit form from a theoretical point of view (because of the logical view of the distribution of the disturbances as normal according to the central limit theorm), it is more complex and computationally demanding (Ben-Akiva and Richards 1975). The logit model is the most extensively used model for choice situation because it is simple to calibrate (McFadden et al. 1977) and a large number of variables can be included and analyzed. Computer

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[1]Although the linear form is convenient, it is not essential to the development of the logit model. Lerman and Louviere (1979) used a logit model with nonlinear utility function as reported by Horowitz (1981).

programs that estimate parameters of the logit model are also available. All of these reasons make the logit model very attractive for use in this research.

3.2.3 Binary Logit Model

The form of the Binary Logit Model:

$$P_n(i) = \frac{e^{V_{in}}}{e^{V_{in}} + e^{V_{jn}}}$$

In case of "event" and "non-event" alternatives as in gap acceptance situation (accept and not accept a gap), the logit model takes the following form:

$$P_n(i) = \frac{e^{V_{in}}}{1 + e^{V_{in}}}$$

where $V_{in} = \beta_1 X_{in1} + \beta_2 X_{in2} + \beta_3 X_{in3} + \ldots\ldots\ldots + \beta_k X_{ink}$

with X_{in} representing the observed variables that describe the attributes of a gap and driver's characteristics. β_i are the coefficients to be estimated. The logit coefficients are typically estimated by the Maximum Likelihood Estimation (MLE) procedure which is discussed later in this chapter.

Building a Logit Model

It is important to know that the model building is an iterative process that includes the following three steps:

Step 1: Model specification

This step starts with certain assumptions regarding model structure. These assumption can be consistent with a large number of model specifications,

Step 2: Model estimation

Model is estimated using the method of maximum likelihood estimation (MLE) technique,

Step 3: Model Calibration

Model is calibrated using a variety of formal and informal tests to help in narrowing the range of alternative models. Among those models which are consistent with the assumptions, the model that performs best according to the goodness of fit measures and statistical significance tests, is selected.

3.3 MODEL SPECIFICATIONS

The first step of building a logit model is to start with an assumption regarding model specifications. This section provides a list of the variables that were initially considered for different model specifications in this research. Criteria for formulating different model specifications as well as possible logical formulations are also included.

3.3.1 Variables Included in Model Specifications

From the review of the literature, a list of candidate factors that potentially influence a driver's decision to accept or reject a gap between two successive vehicles of a conflicting traffic stream was assembled. These factors represent both gap attributes and driver characteristics. The focus of this research, as mentioned in Chapter 1, is on the major factors. A list of these factors and their descriptions are included in Table 3.1. These factors are classified into the following categories:

1- Factors related to raffic such as gap size, delay, opposing traffic flow, presence of vehicle behind, speed and type of opposing vehicle

2- Factors related to the driver and the turning vehicle such as driver gender, age, presence of passengers in the turning vehicle, and acceleration capability of turning vehicle,

3- Factors related to geometry of the intersection such as number of opposing lanes to be crossed and their width. Location specific constants were added as variables to capture any effect of location characteristics on driver behaviour.

Table 3.1 Factors used in model specifications and their description

Factors	Description	Form
Gender	Left turning driver: male or female	0 or 1
Age	Estimated age category of left turning driver: young; middle; old	0 or 1
Presence of passengers	presence of passengers in the turning vehicle in two categories: yes; no	0 or 1
Acceleration capability of the turning vehicle	acceleration capability in three categories: low; average; high	0 or 1
Queue delay	time spent in queue, from joining the queue until reaching the head of the queue	value (seconds)
Front delay	time at the head of queue waiting for a gap	value (seconds)
Total delay	Time spent in queue and waiting for a gap	value (seconds)
Time gap	headway from front to front of two successive opposing vehicles	value (seconds)
Space gap	distance from front to front of two successive opposing vehicles	value (meters)
Speed of the opposing vehicle	speed of the opposing vehicle ending a gap	value (km/h)
Type of the opposing vehicle	Vehicle ending a gap in 4 categories: Passenger vehicle; Truck/Bus; Motorcycle; Bicycle.	0 or 1
Number of rejected gaps	Number of previously rejected gaps up to each choice situation	integer number
Microscopic flow of the opposing traffic	Opposing flow between the arrival time of left turning vehicle at the head of queue and the arrival of vehicle ending accepted gap	value (vehicles/ min)
Presence of vehicles	Presence of vehicles in queue behind the turning vehicle in two categories: yes; no	0 or 1
Number of lanes	Number of opposing lanes to be crossed	integer number
Width	Width of opposing approach to be crossed	Value (m)

Other factors, that might affect driver behaviour, were not considered in this research for the following reasons:

1- Unobservable: such as in-vehicle environment, psychological and physiological factors, and purpose of the trip,

2- Difficult to observe: such as type of passengers in the car, or the lane in which the opposing vehicles travel,

3- It would add more dimensions to the studied problem: such as presence of pedestrians, weather conditions, light conditions, or effect of right turns from the major street into the minor street.

3.3.2 Model Specifications Initially Considered

Because the "best" model form was not known at the initial model development stages, vast numbers of gap acceptance model forms are possible and can be used as an investigative tool. The potentially vast number of gap acceptance models had to be reduced. Only the logical combinations of variables were considered as shown in Figure 3.2.

Each model represents more than one model specification by including or eliminating some variables or by splitting one variable into several variables. As shown in Figure 3.2, some variables such as age and gender of driver, presence of passengers, type of opposing vehicle and acceleration capability were initially included in all tested models, with different logical combinations of other variables (e.g. either time gap or space gap is included in one model).

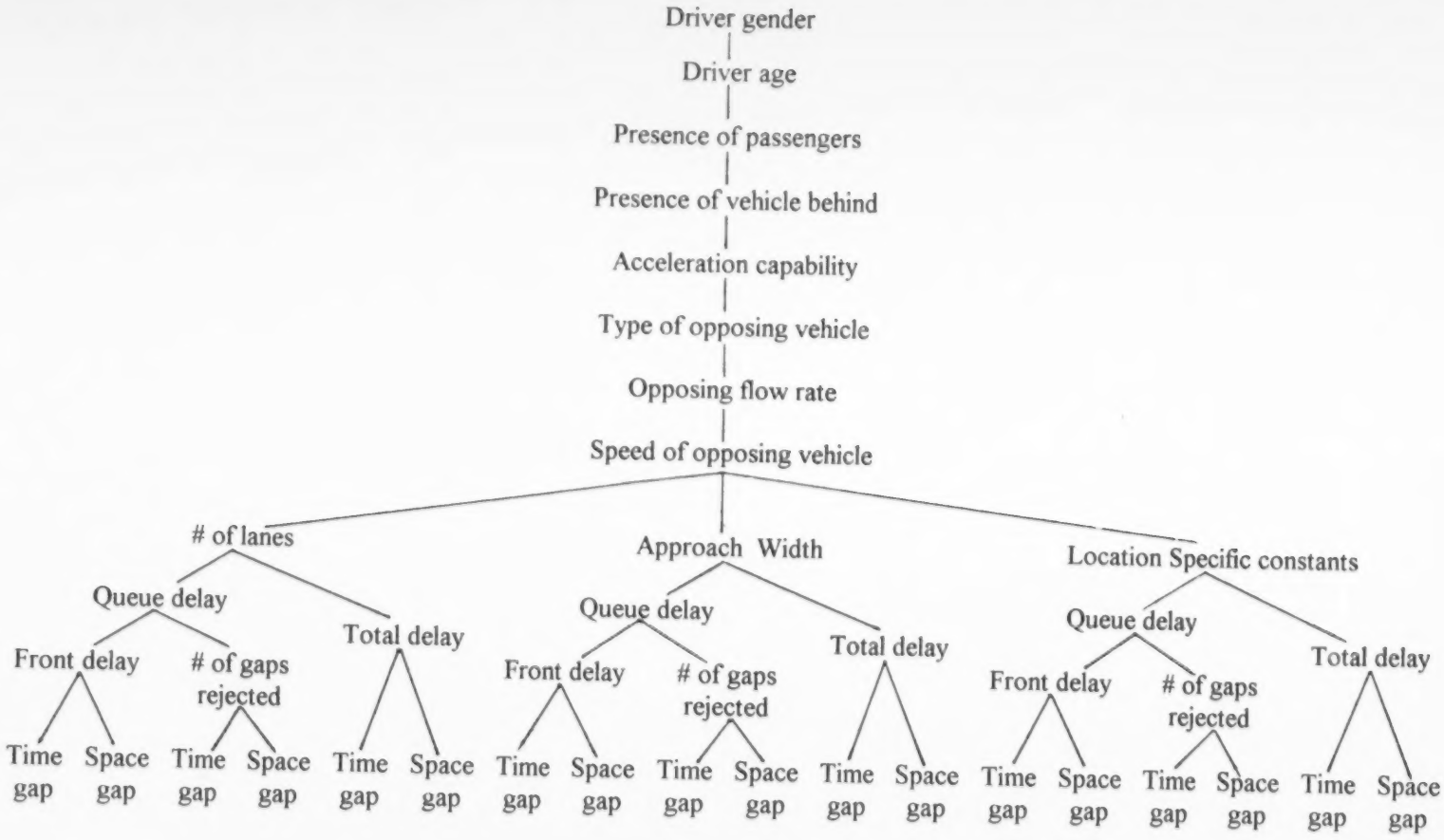

Figure 3.2 Different Model Specifications Initially Considered

3.4 MODEL ESTIMATION

3.4.1 Introduction

The logit coefficients (β) are typically estimated by the Maximum Likelihood Estimation (MLE) method. For the estimation (estimating the value of β) the following detailed data about each choice situation were needed:

1- Numerical representation of gap attributes,
2- Numerical representation of driver's characteristics,
3- An indication of the alternative chosen by the driver.

Sample Size Requirement: Koppelman and Chu (1983) studied the effect of sample size on the precision of estimating mode choice model parameters. They compared estimated parameter values for different sample size with the population parameters (full sample). They reported that the sample size required to obtain choice model parameter estimates that are reasonably close to the true population parameter, is at least on the order of 1,000 to 2,000 observations.

3.4.2 Maximum Likelihood Estimation Technique

The following section is a review of the maximum likelihood technique used in this research, as described in Ben-Akiva and Lerman (1985).

For any sample of N observations, the likelihood of the entire observations is the product of the likelihood of the individual observation. The likelihood function is as follows:

$$L^* = \prod_{n=1}^{N} \prod_{i \in C_n} [P_n(i)]^{y_{in}}$$

where $P_n(i) = \dfrac{e^{V_{in}}}{\sum_{j \in C_n} e^{V_{jn}}}$,

y_{in} = variable defined as 1, if person chooses alternative i,
0, otherwise.

In case of binary choice C_n : {i,j}

$$L^* = \prod_{n=1}^{N} [P_n(i)]^{y_{in}} \; [P_n(j)]^{y_{jn}}$$

$P_n(j) = 1 - P_n(i)$, $\qquad y_{jn} = 1 - y_{in}$

It is easier to maximize the logarithm of L^*, denoted as L (log likelihood) rather than L^* itself.

$$L = \sum_{n=1}^{N} [y_{in} \log P_n(i) + y_{jn} \log P_n(j)]$$

$P_n(i)$ is a function of $\beta_1, \beta_2, \ldots\ldots\ldots, \beta_k$. Therefore, it is required to find the values of $\beta_1, \beta_2, \ldots\ldots\ldots, \beta_k$ that maximize the log likelihood. This can be done by setting the first derivatives of L with respect to each of β's equal to zero as follows:

$$\frac{\partial L}{\partial \beta_k} = \sum_{n=1}^{N} \left[y_{in} \frac{\partial P_n(i)/\partial \beta_k}{P_n(i)} + y_{jn} \frac{\partial P_n(j)/\partial \beta_k}{P_n(j)} \right] = 0$$

To find the maximum likelihood estimate, it is required to solve K nonlinear equation in K unknown ($\beta_1, \beta_2, \ldots\ldots\ldots, \beta_k$). One way for getting estimates for β' s, is using the Newton Raphson method as described in Ben-Akiva and Lerman (1985). The method is an iterative process. Each iteration attempts to find a point that is having greater likelihood. Various software packages for estimating multinomial logit model are available in the market. In this research the NTELOGIT (1992) program was used.

3.4.3 Description of the Estimation Program

NTELOGIT (1992) is a window-base program for estimation of the parameters of the multinomial logit (MNL) model using Maximum Likelihood Technique. The program is composed of two parts.

The first part is used to define the choice problem as follows:

a) Description of data file by entering the following information:
- Name of data file,
- Number of alternatives in the data file,
- Name of the columns in the data file.

b) Specification of the model to be estimated by specifying variables which are to be included

The second part is estimation of the model. The program produces a report containing model statistics and model parameter estimates.

Input and output file description are discussed in the following sections.

Input Data File Description

The data files used for model estimation by NTELOGIT program had to be in special format. Each record or line of the data file contained the following columns:

1- Group identification which is the basic unit of observation,
2- Alternative identification:
= 1 for alternative 1 "Accept a gap",
= 2 for alternative 2 "Reject a gap"
3- Observed choice frequency
= 1 if an alternative chosen
= 0 if an alternative not chosen
4- Independent variables columns:

For alternative 1 (accept), these columns are an alternative specific constant column followed by independent variables' columns. For alternative 2 (not accept), all variables are zeros as shown in Table 3.2.

Table 3.2 Description of Data File Required for Model Estimation by NTELOGIT Program

Group #	Alternative #	Choice frequency	Independent Variables
1001	1	1	(.....)
1001	2	0	0
1002	1	0	(.....)
1002	2	1	0

Output File Description

The program generates a model estimation report that contains the following information:

- Name of the data file used and the model specification file
- Convergence criteria (criteria used by the program to decide when to stop iterating),
- Number of iterations,
- Overall model statistics (log likelihood values, goodness-of-fit statistics)
- Estimated parameters, standard error of the parameter, and t-statistic for the hypothesis that the parameter is equal to zero,
- Parameter covariance matrix,
- Prediction success table.

3.5 MODEL CALIBRATION

At the initial stage of model development the functional form of the gap acceptance model was not known. Therefore, several models were explored. The models were tested to see whether the result seemed reasonable. Tests included informal and formal statistical tests. The principles of these tests are discussed in the following sections.

3.5.1 Informal tests

The informal test is used to examine the value and sign of the parameter estimates, as follows:

1- Examine the sign of the parameter estimate which should be in agreement with our expectation. (e.g. in gap acceptance model, a negative sign is expected for the estimated parameter for the speed of main stream opposing vehicles and a positive sign is expected for the estimated parameter for the gap size).

2- Examine the relative values of the parameter estimates appearing in the same utility function. These relative values have to be checked to see if they reflect our own expectations. It is also desirable to compare these values with those from similar models calibrated before in other places, or at other times, if available.

3.5.2 Statistical tests

Testing the Estimated Parameter

t-statistics: This test is used to examine whether an estimated parameter in the model differs from some known constant, often zero as follows:

Null hypothesis $H_0 : \beta_i = 0$

Alternate hypothesis $H_a : \beta_i \neq 0$

$$t - \text{statistic for an estimated parameter} = \frac{\text{estimated parameter value}}{\text{estimated standard error}}$$

t-statistics at 0.10 (or 0.05) significance level is ±1.65 (±1.96). If the calculated t-statistic is outside the range ±1.65, we can reject the null hypothesis that the estimated value for the parameter equals zero at 10% level of significance (at 90% level of confidence).

Using Variance-Covariance Matrix Information : This test can be used to test the linear relationship between parameters (test the difference between two parameter values).

Null hypothesis $H_0 : \beta_1 = \beta_2$
Alternate hypothesis $H_a : \beta_1 \neq \beta_2$

$$t\text{-}statistics = \frac{\beta_1 - \beta_2}{\sqrt{\text{var}(\beta_1 - \beta_2)}}$$

$$= \frac{\beta_1 - \beta_2}{\sqrt{\text{var}\,\beta_1 + \text{var}\,\beta_2 - 2\,\text{cov}\,\beta_1, \beta_2}}$$

If the calculated t-statistic is outside the range ± 1.65, we can reject the null hypothesis that the two parameter values are equal at 10% level of significance (at 90% level of confidence).

The Log-Likelihood Chi-Squared Significance Test: This test is used as follows (Hauser, 1978):

1- It tests the null hypothesis that all the parameters are zero. The test statistic is:

$$X^2 = -2\,[\,L(0) - L(\beta)]$$

where: $L(0)$ = log likelihood for the model with all β's =0, (equal likelihood model)
$L(\beta)$ = log likelihood for the estimated model

The calculated value varies according to X^2 (Chi-square) distribution with degree of freedom equal to the number of parameters included (k).

2- It tests the null hypothesis that all the parameters, except for the alternative-specific constants are zero, the test statistic is:

$$X^2 = -2\,[\,L(c) - L(\beta)]$$

where $L(c)$ = log likelihood for the model with only alternative specific constants (market-share proportional model).

The calculated value varies according to X^2 distribution with "K–J+1" degree of freedom, where J is the number of available alternatives.

3- It tests the null hypothesis that certain restrictions to the estimated model are true, provided that the restricted model is a subset of the tested model. The test statistic is:

$$X^2 = -2 [L(\beta_R) - L(\beta_U)]$$

where $L(\beta_R)$ = log likelihood for the restricted model,
$L(\beta_U)$ = log likelihood for the unrestricted model

The calculated value varies according to X^2 distribution with degree of freedom equal to the difference in degree of freedom between the unrestricted model and the restricted model.

The log-likelihood chi-squared significance test can reject a null hypothesis, but it does not give an indication of how well a model predicts nor how well the model compare to other models unless one model is a restriction of the other (Hauser, 1978). In this case, the following test is used.

Testing the Overall Model Fit

After examining the signs, the relative values, and the significance of the parameters estimated, the following tests were used to assess the goodness of fit of the overall model.

Likelihood Ratio Index

There are different forms of the likelihood ratio index that is used to compare goodness of fit of more than one model specification as follows:

$$\rho^2(0) = 1 - \frac{L(\beta)}{L(0)}$$

where $\rho^2(0)$ is the likelihood ratio index, similar to R^2 used in regression. It compares the performance of the estimated model to the performance of an equal likelihood model. There are no general guidelines for the $\rho^2(0)$ value, but the closer to 1, the better the model fits a given data. When comparing two model specifications, the model with the higher $\rho^2(0)$ value is considered to be better.

A shortcoming of this index is, for the same estimation data set, $\rho^2(0)$ will always increase or at least stay the same whenever new variables are added to the utility function (Ben-Akiva and Lerman, 1985). For this reason $\rho^2(0)$(AIC) was introduced.

$\rho^2(0)$(AIC) is the same as $\rho^2(0)$ except that it accounts for the number of parameters estimated "K".

$$\rho^2(0)(AIC) = 1 - \frac{L(\beta) - K}{L(0)}$$

where [L(β) – K] is known as the Akaike information criterion.

Horowitz (1982) used the modified ρ^2 similar to the above equation except subtracting K/2 instead of K. Horowitz concluded that when comparing two model specifications, the modified likelihood ratio index has a high probability of indicating that the model with a slightly higher modified likelihood ratio index is superior to other models with lower values.

Tardiff (1976) proved that $\rho^2(0)$, contrary to expectations, does not have a lower bound equal to zero. The minimum value depends on the relative proportions of sampled individuals selecting the various alternatives. The dependency on the sampled proportions prevents comparison of indices resulting from different samples. Tardiff recommended another likelihood ratio index that is more appropriate than $\rho^2(0)$ statistic. The index compares the logarithm of the likelihood function of the hypothesised model, to the logarithm of the likelihood function of the constant model in the binary model (logarithm of the likelihood function of the model with alternative specific dummies in the multinomial model). The index takes the following forms:

$$\rho^2(c) = 1 - \frac{L(\beta)}{L(c)} \quad \text{or}$$

$$\rho^2(c)(AIC) = 1 - \frac{L(\beta) - K}{L(c)}$$

where $\rho^2(c)$ is the likelihood ratio index that compares the performance of the estimated model to the performance of the market-share proportional model (constant only model).

$\rho^2(c)(AIC)$ is the same as $\rho^2(c)$ except that it accounts for the number of parameters estimated "K".

L(c) = log likelihood for the model with only alternative specific constant.

Based on the previous review of different forms of the likelihood ratio index, the following forms are used in this research:

$\rho^2(0)(AIC)$ is used when comparing two models estimated using the same set of observations.

$\rho^2(C)(AIC)$ is used when comparing two models estimated using different sets of observations (with different proportions of sampled individuals selecting the various alternatives).

Percent-Correctly-Predicted Statistic

Percent correct is defined as, percentage of the observed choices that are predicted to choose the observed alternative. The larger the value percent correct, the better the model. Horowitz (1982) mentioned that the percent-correctly-predicted statistic is a less useful measure for comparing models than the modified likelihood ratio index. He also mentioned that the percent correct statistic may fail to distinguish between correct and incorrect models.

3.6 SUMMARY

In this research, gap acceptance is viewed as a series of binary choices. The choices are either to wait or to proceed, i.e., to reject or accept an available gap. The investigation method models the choice from a set of discrete alternatives using the principle of utility maximization. The driver is assumed to accept the gap if the utility of accepting that gap is higher than the utility of rejecting it. The utility of a gap in a given situation is a function of the attributes of the gap and the characteristics of the driver. The linear-in-parameters function is the most convenient form and was the only model form considered in this research. The binary logit is used for this research.

The parameters of the model are estimated using maximum likelihood with a set of observations that describe choice behaviour in terms of the attributes of the alternative, characteristics of the individual driver, and the choices made. "NTELOGIT" (1992) is a software package that was chosen for parameter estimation of the logit model.

Since many functional forms of the gap acceptance model would be possible, several were tested and compared to choose those with superior performance. The relative value of parameters in these superior models are used to provide an indications of the relative importance of each variable on a drivers' decision as described in Chapter 6.

Emphasis is placed on an understanding driver's decision, by examining the effects of several variables on that decision, rather than the formulation of an exact prediction model which could be used in capacity or delay studies.

CHAPTER 4

DATA COLLECTION

4.0 INTRODUCTION

For estimating the parameters of the logit model using the maximum likelihood estimation (MLE) technique, detailed data about each choice situation were needed, as described in Chapter 3. Reviewing the literature showed that no previous studies tried to collect such required data on that microscopic level. It was decided to collect required data on driver characteristics and system attributes as well as driver's revealed preference for each gap situation from direct field observation. Five intersections were selected and surveyed for this purpose.

The purpose of this chapter is to document the data collection phase of this research. In Section 4.1, the data required for model estimation are described. Section 4.2 provides criteria for selecting study locations as well as a description of the selected locations. Section 4.3 includes a description of the data collection method and procedures used for data collection and entry.

4.1 REQUIRED DATA

A set of variables that may influence a driver's choice to accept or reject a gap was identified. These variables represent driver's characteristics and attributes of the gap. For each choice situation, numerical quantification of these variables as well as an indication of the choice made by the driver were required. The following is a list of the required data for each choice situation:

1- Driver gender
2- Driver age
3- Presence of passengers in turning vehicle
4- Acceleration capability of left turning vehicles
5- Queue delay
6- Front delay
7- Gap size

8- Speed of opposing vehicle
9- Type of opposing vehicle
10- Number of rejected gaps up to the subject gap
11- Microscopic flow rate
12- Presence of vehicle behind
13- Number of lanes to be crossed and the width,
14- Choice made (accept or reject)

Some of these variables could not be measured directly, such as the speed of each opposing vehicle that ends a gap and the microscopic flow rate experienced by each left turning vehicle. To obtain the required data, the following events and information were recorded simultaneously:

For major stream opposing vehicles:

- Arrival time at two points of a fixed distance apart,
- Type of vehicle, either passenger car, truck or bus, motorcycle, or bicycle as described in Chapter 1.

For the left turning vehicles:

- Arrival time at the end of the queue,
- Arrival time at the head of the queue,
- Arrival time at the conflict point,
- Gender and age group of the driver, presence of passengers in the turning vehicle and vehicle's acceleration capability as described in Chapter 1.

4.2 STUDY LOCATIONS

4.2.1 Site Selection Criteria

The scope of the research was limited to unsignalized T-intersections. Only the left turning movement from a major street into a minor street was studied. The criteria for site selection included the following:

1) All intersection approaches should be relatively flat (no noticeable grade) with no restrictions to the sight distance,

2) Intersections should be at a sufficient distance from the nearest signalized intersections to cause randomness of arrival for the opposing traffic (about 1.6 km) (HCM 1993). For intersections that are closer than this distance, the phasing of the upstream intersection should provide right and left turning movements that randomize the arrival.

3) The left turning movement from the major street into the minor street should be made from an exclusive left turn lane,

4) The left turning and opposing traffic volumes should provide a range of gap sizes on the major street and a range of delays to the turning vehicles.

4.2.2 Description of Study Locations

A large number of T-intersections without traffic signals were examined to choose suitable locations for this study. The following five intersections were selected, four of them within the City of Edmonton boundaries and one approximately 15 kilometers west of the Edmonton boundary in the Town of Stony Plain.

1- 23 Avenue location (23Ave), intersection of 23 Avenue and 110 Street,
2- 99 Street location (99St), intersection of 99 Street and 66 Avenue,
3- Keillor Road location (KE), intersection of Fox Drive and Keillor Road,
4- West Edmonton Mall location (WE), West Edmonton Mall entrance from 90 Avenue between 174 and 175 Street,
5- Stony Plain location (SP), intersection of Highway 16 and South Park Drive, Town of Stony Plain.

The study locations are shown in Figure 4.1. Directions of the subjected left turning movement at the study locations are given in Table 4.1.

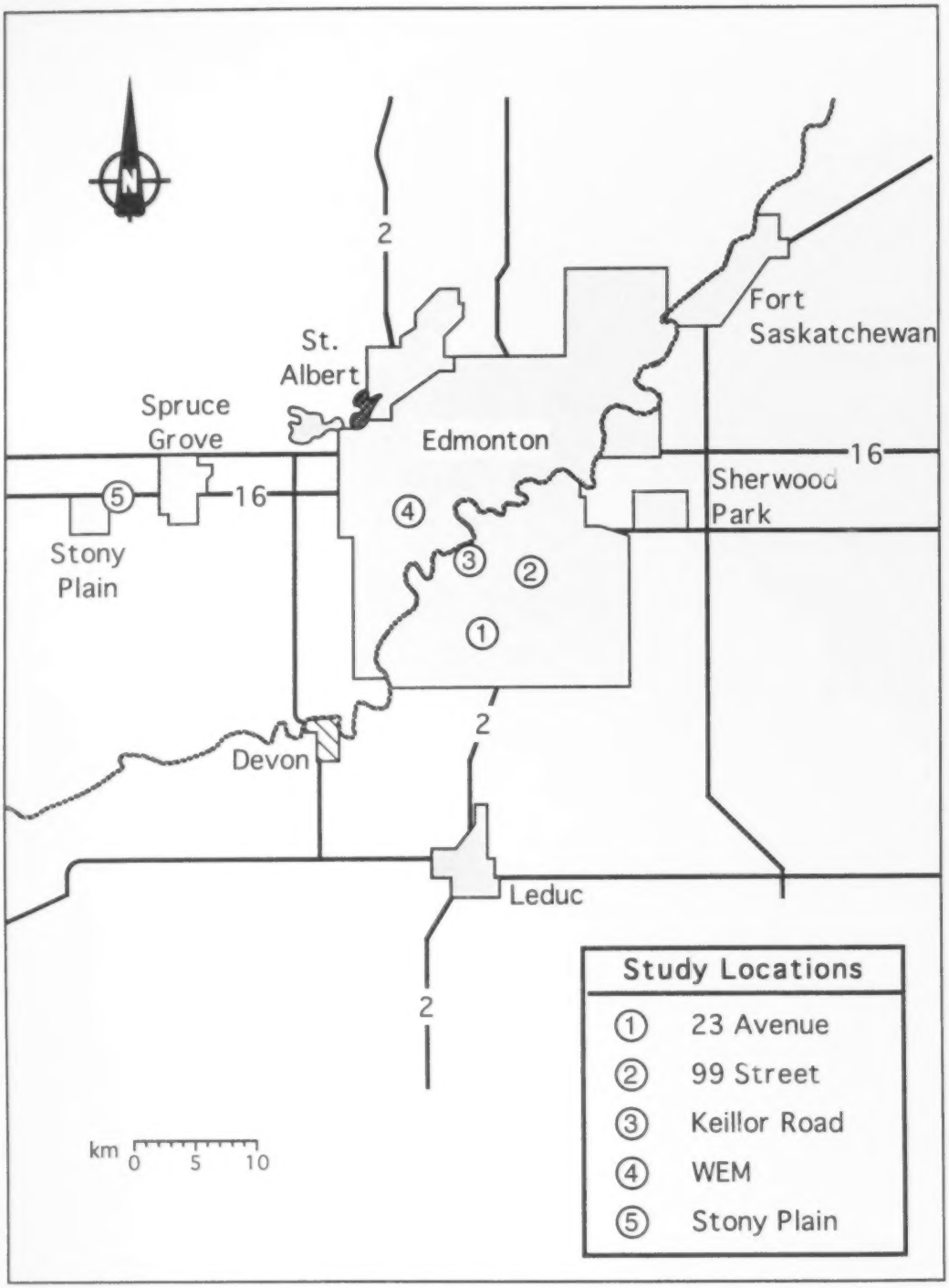

Figure 4.1 Locations of the Studied Intersections

Table 4.1 Directions of Left Turning Movement at the Study Locations

Intersection	Studied Movement	
	From	To
23 Avenue	23 Avenue	110 Street
99 Street	99 Street	66 Avenue
Keillor Road	Fox Drive	Keillor Road
West Edmonton Mall	90 Avenue	Entrance between 174 and 175 Street
Stony Plain	Highway 16	South Park Drive

23 Avenue Location

The major street, 23 Avenue, is a 4 lane major arterial road. It has two lanes in each direction that are separated by a curbed median with an exclusive left turn lane at the intersection. For the opposing traffic, downstream of the intersection, there is a third lane that is strictly for bus use. Posted speed limit on 23 Avenue is 60 km/h. The sources of opposing traffic are the eastbound through movement along 23 Avenue, and the left turn movement into 23 Avenue from 111 Street, which is also a major north/south arterial road, allowing for noticeable random arrival. The intersection is approximately 220 m away from the nearest intersection at 111 Street that allows subjected left turning drivers to see the signal light indication at that intersection. There is no restriction to the sight distance at this location. There are few pedestrian crossings to 23 Avenue from the Heritage Mall, located north of the intersection.

The minor street, 110 Street, is a two-lane two-way road into shopping and a multi-family residential area. There is parallel parking on both sides of the street. Left turning vehicles from 110 Street, and the right turning vehicles into 110 Street, did not seem to interfere with the subjected movement.

A layout of the intersection is shown in Figure 4.2.

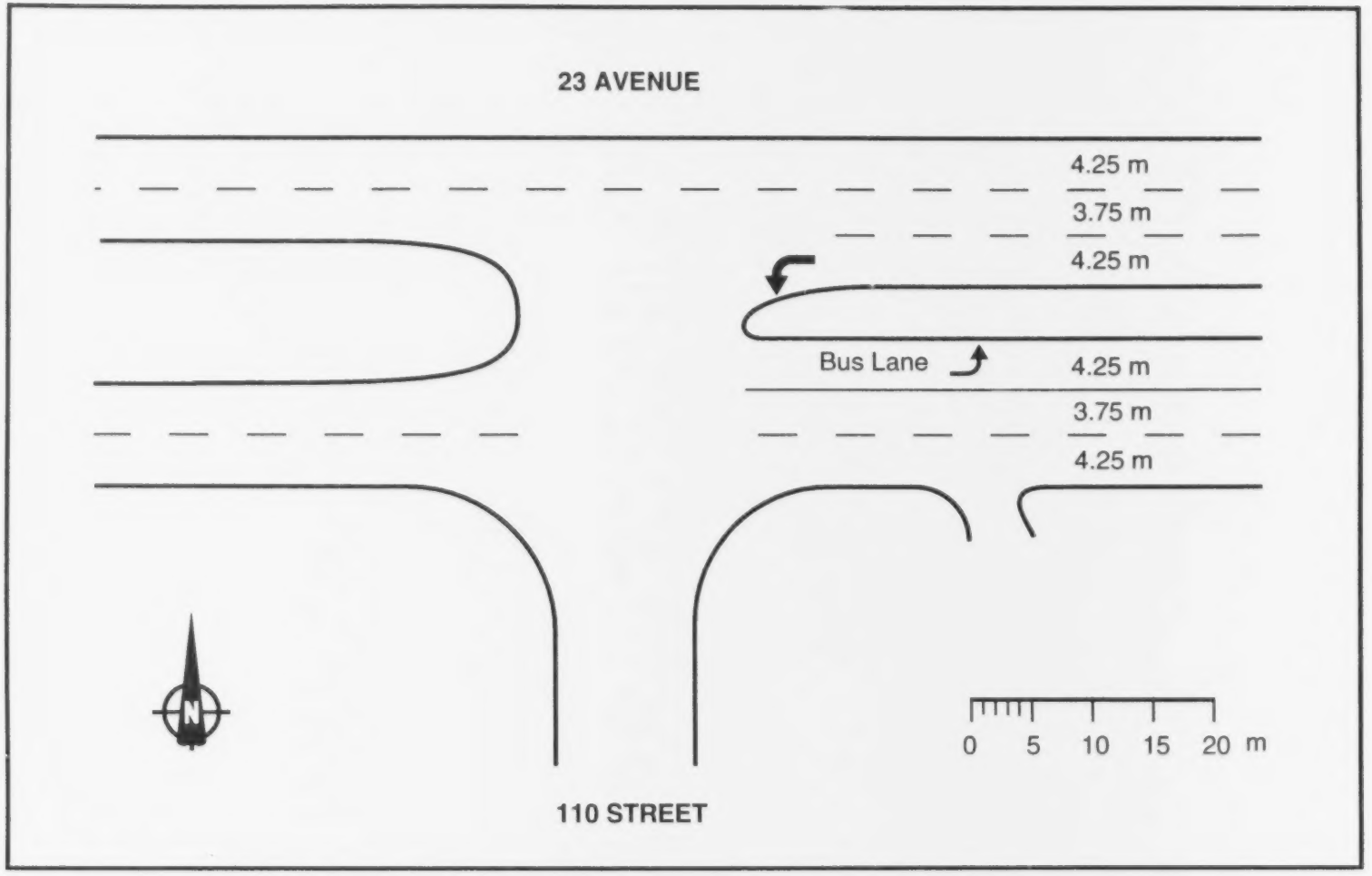

Figure 4.2 Layout of 23 Avenue and 110 Street Intersecttion

99 Street Location

The major street, 99 Street, is a 4 lane divided arterial road. There are two lanes in each direction separated by a curbed median with an exclusive left turn lane at the intersection. 99 Street is a major truck route that passes through a major light-industrial area. Occasionally trucks and buses at this location obscure the left-turning drivers' view of opposing traffic. There are buses that stop on 99 Street north of 66 causing the vehicles traveling behind to slow down. The distance to the nearest signalized intersection is approximately 300 meters. Sources of opposing flow are the northbound through traffic, and the left turn traffic from 63 Avenue into 99 Street, discharging from an advanced phase. At the studied location, the posted speed limit on the major street is 50 km/h.

The minor street, 66 Avenue, is a two-lane, two-way road through a residential/ commercial area. The right turn to 66 Avenue and the left turn from 66 Avenue seemed to interfere with the studied movement. A layout of the intersection is shown in Figure 4.3.

Keillor Road Location

The major street, Fox Drive, is a four-lane arterial road. The two directions are separated by a curbed median with exclusive left and right turn lanes at the intersection. Upstream the intersection at Fox Drive, there are both horizontal and vertical curves but they do not obstruct the observation of opposing traffic. The posted speed limit on the major street is 70 km/h. It is noteworthy that there is significant speed enforcement in both directions. The nearest signalized intersection is the intersection of Fox Drive and Belgravia Road; approximately 1.3 km from the surveyed location.

The minor street, Keillor Road, is a two-lane two-way road with 4 lanes separated by a curbed median at the intersection. The posted speed limit on Keillor Road is 50 km/h.

The majority of the subjected left turning traffic was using Keillor Road as a short cut from the South-West area of the city to the university and downtown areas. The short cut was eliminated shortly after the survey was completed. The layout of the intersection is shown in Figure 4.4.

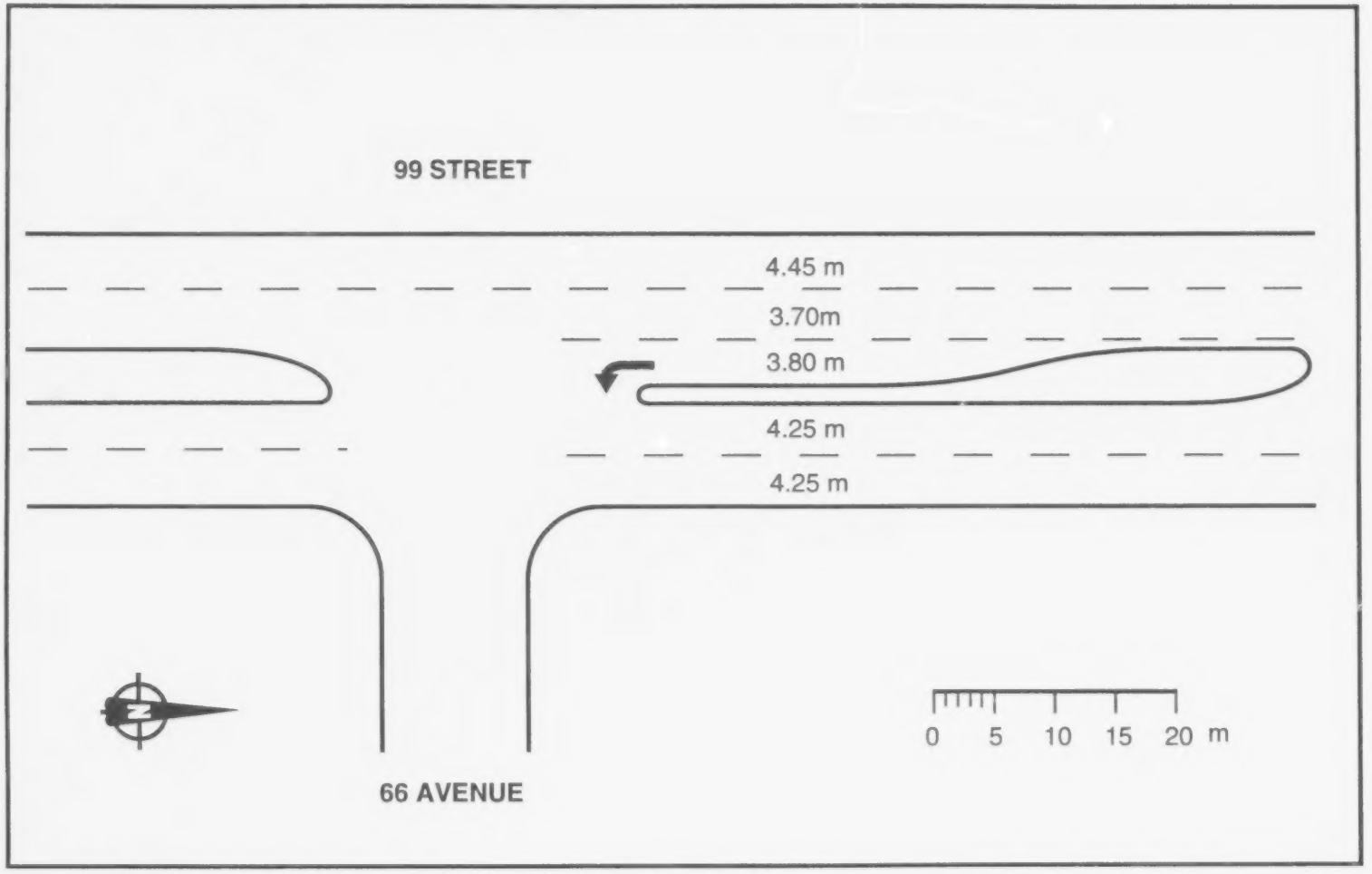

Figure 4.3 Layout of 99 Street and 66 Avenue Intersection

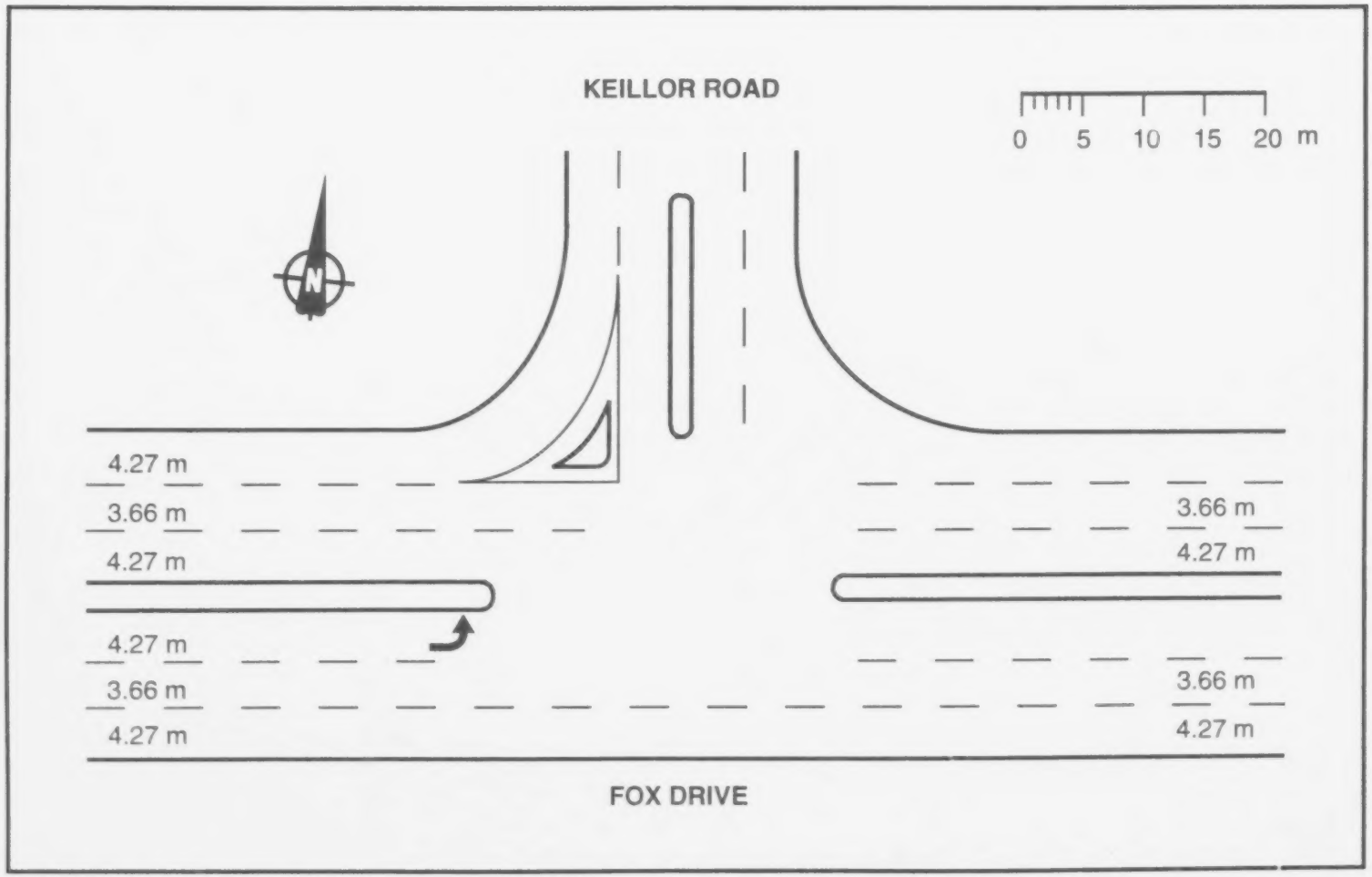

Figure 4.4 Layout of Fox Drive and Keillor Road Iniersection

West Edmonton Mall Location (WEM)

The major street, 90 Avenue, is a 4 lane undivided road. The road has two lanes in each direction with an exclusive left turn lane at the intersection. Posted speed limit on the street is 50 km/h. The upstream signal is actuated by the arrival of vehicles leaving the Mall. The distance to that signalized intersection is only 130 meters. There are occasionally few pedestrians crossing 90 Avenue from an undesignated pedestrian-crossing area, causing vehicles to stop or slow down.

The minor street, an entrance to WEM between 174 and 175 Street, is a two-lane two-way ramp to the second level of the Mall. The ramp is fairly steep. The transition from the road level to the ramp is very abrupt causing the left turning vehicles to slow down. The right turn into the ramp seems to interfere with the subjected movement. Layout of the intersection is shown in Figure 4.5.

Stony Plain Intersection

The major road, Highway 16, is a 6 lane divided highway; three lanes in each direction separated by a wide median with exclusive right and left turn lanes at the intersection. The arrival of the opposing flow is totally random as described in Chapter 5. There is a large speed variation along the highway. The posted speed on Highway 16 is 100 km/h, however, it is 80 km/h at this location.

The minor road, South Park Drive, is a 4-lane undivided road into a recreational/ single family residential area.

The occasional left turn from South Park drive to Highway 16 seems to influence the observed movement. There are no obstructions to the sight distance at this location. There are no pedestrians crossing.

The layout of the intersection is shown in Figure 4.6.

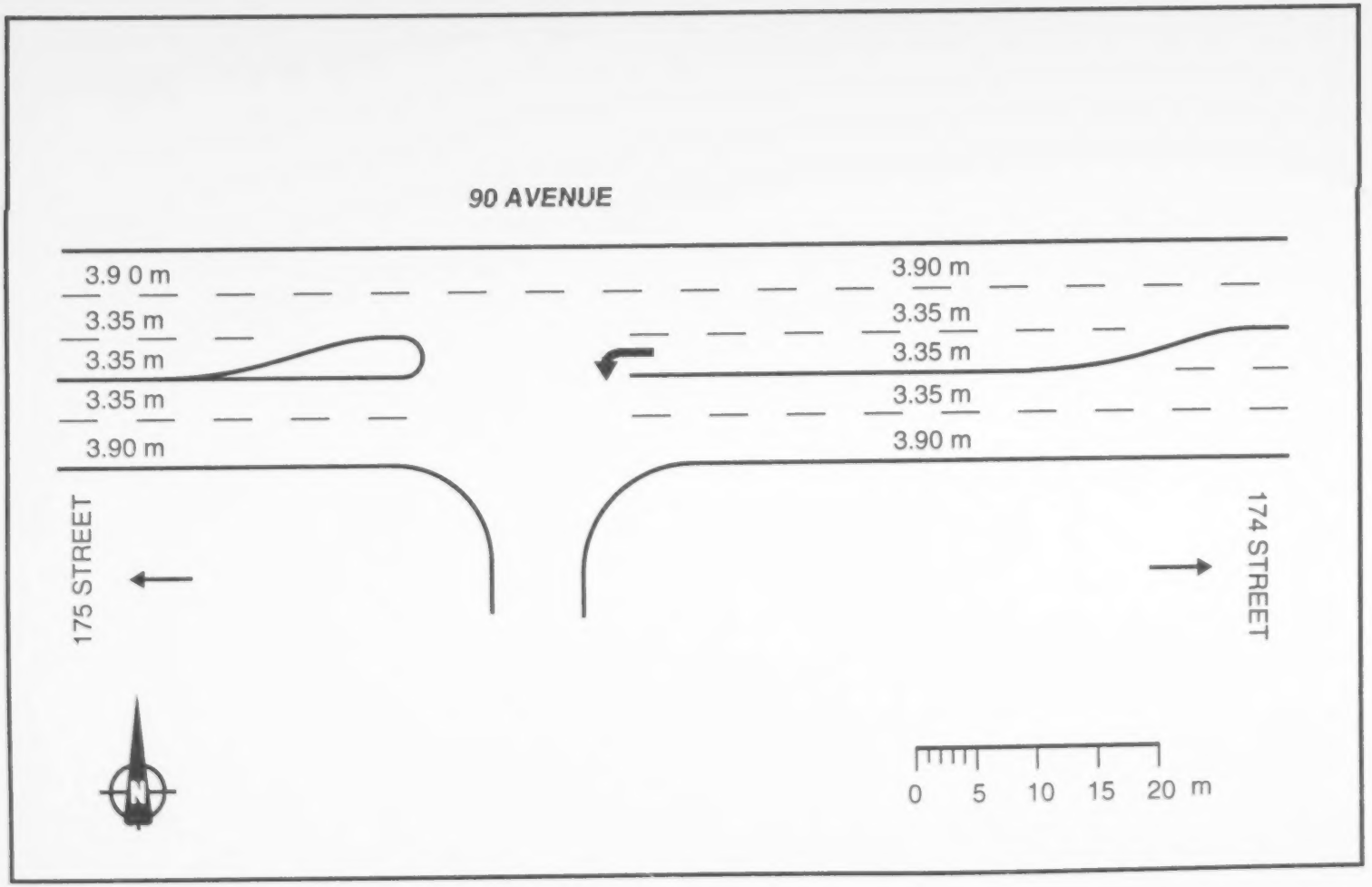

Figure 4.5 Layout of West Edmonton Mall Location (WEM)

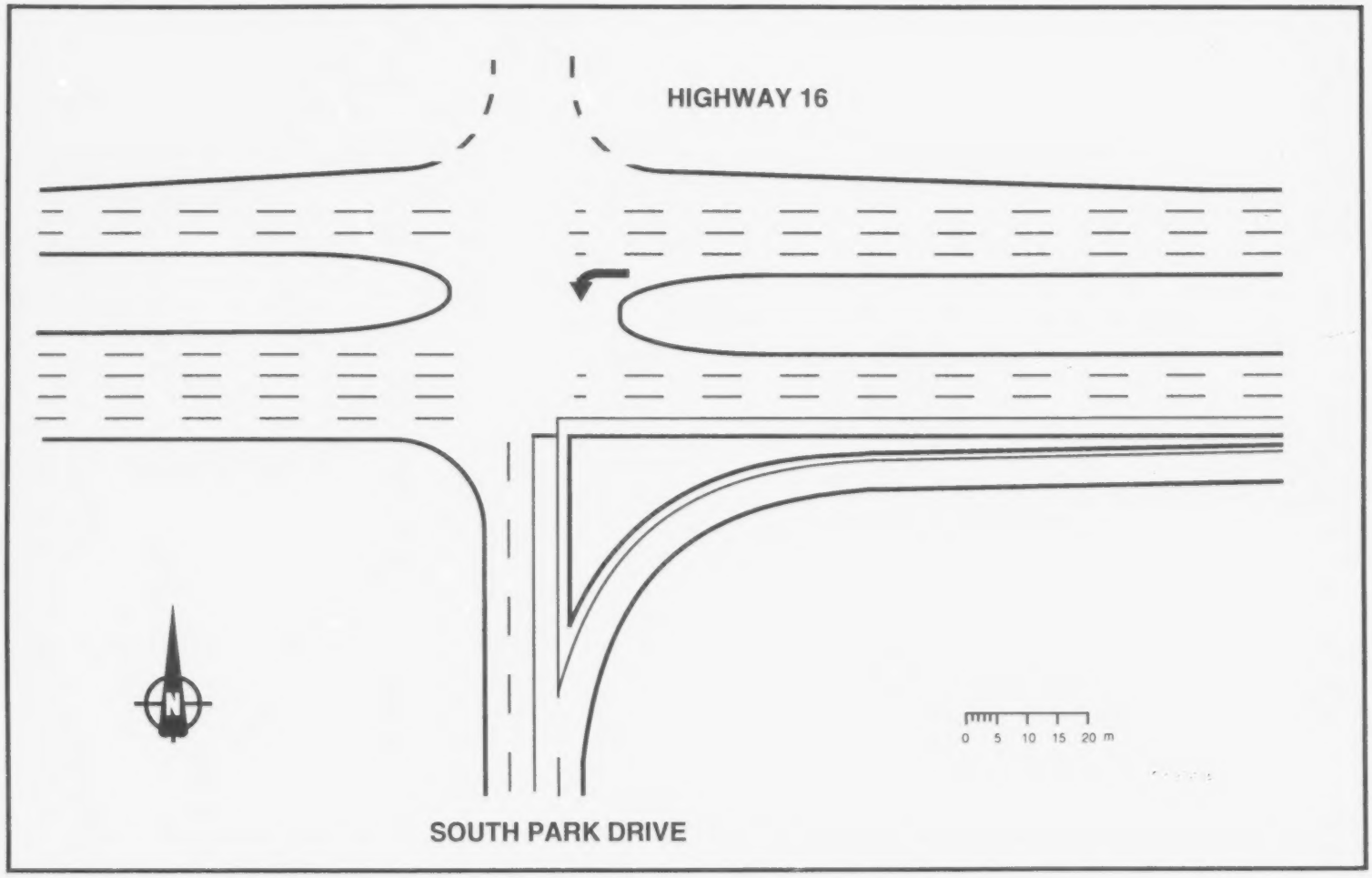

Figure 4.6 Layout of Stony Plain Intersection

4.3 DATA COLLECTION PROCESS

Due to the complexity of the data required, a combined use of video-camera in the field and personal computer in the office was chosen for collecting the required data. This technique was chosen even though it requires considerable time to extract the data from the original tapes. A pilot survey was conducted at one intersection as a preliminary step for collecting a complete data set to suit the purpose of this research. Based on the experience gained from that pilot survey, data from all locations were collected later. The following sections provide an overview of the pilot survey and a description of the data collection procedures.

4.3.1 Pilot Survey

A pilot survey was conducted at the intersection of 99 Street and 66 Avenue as a trial for collecting the required data. Data collection was limited to an afternoon peak period. Data were collected using a video camera, JVC GRS707. The first trial was done on Thursday, February 6, 1992. The intersection was videotaped and the tape was analyzed later in the office. After viewing the video tape, the following problems were noticed:

1- The videotaping lasted for only a short period of time because of the below-zero temperature that caused the camera's battery to discharge after 15 minutes of use instead of 45 minutes.

2- The camera's view range did not cover the whole required area. The view should have covered the movement of left turning vehicles from the major street into the minor street since they join the queue until they leave the intersection. This area should also have included the movement of the conflicting major-stream through vehicles, as they passed through the intersection.

3- Driver characteristics, presence of passengers with the driver, as well as acceleration-capability group of the turning vehicle could not be identified on the tape.

To overcome the view range problem, a wide angle lens was attached to the camera for the purpose of this research. A spare battery or another power supply was also

used for longer recording periods. Driver characteristics, presence of passengers and acceleration capability could be observed only from a short distance on site. Therefore, it was decided to use two short-range radios (walkie-talkies). One walkie-talkie would be operated by an observer standing near the intersection, and the other would be positioned near the video camera microphone.

The same intersection was videotaped for a second time on Thursday, March 12, 1992, for about an hour, using the same video camera fitted with a wide angle lens. The procedures used for this pilot trial were used later for data collection at all intersections as will be described in the following section.

4.3.2 Description of Data Collection Process

The process of data collection can be divided into two phases as follows:

1- Video taping phase,

2- Data entry phase

Videotaping Phase

In this phase data were collected by videotaping each of the chosen intersections. The video camera was set at each intersection so that the view of the camera included all queue activity of major stream left turning vehicles. The view also included the movement of opposing through traffic along a section of the road. This section included a conflict point of left turning traffic with the through traffic (point 1), and any other fixed object such as lamp post or power pole at a reasonable distance from point 1.

Required Equipment and Manpower

- 3 observers
- Portable video camera
- Tripod
- 2 Walkie-talkies
- Power supply
- Measuring tape

A CVHS video camera, JVC GRS 707, mounted on a tripod during recording was used for intersection video taping. The camera was fitted with a wide angle lens for a wider view of the intersection.

The camera was equipped with an electronic viewfinder on which the video picture could be seen continuously during recording in order to make sure that camera range had not been changed. The recorded picture could be played back on the camera's viewfinder to check that the recording was satisfactory. The built-in microphone mounted on the side of the camera allowed any sound to be superimposed on the visual recording.

The camera could be operated either from a rechargeable battery pack or from external power supply, such as a car battery or portable generator (12 V. DC supply via power adaptor). The battery pack proved to be impractical, lasting less than 45 minutes under ideal conditions. Therefore, car battery power supply was used wherever it was possible to get the car near the video camera location; otherwise a portable AC power generator was used.

Video Taping Process

At each site, the camera was located at a distance from the intersection to get the required view. The camera range was adjusted to include preselected reference points such as lamp pole or sign post. Locations of the identified reference points were measured on site and plotted on an intersection map. For intersections that were videotaped more than once, video camera location as well as reference points were changed to get a better view.

Three people were needed. One person operated the video camera. The other people stood near the intersection in such a way that they could observe left turning drivers clearly, without being seen. One of these two observers, holding one walkie-talkie, dictated information about driver's age group, gender, and whether or not there were passengers in the turning vehicle. The second observer identified the type of vehicle and dictated its acceleration capability group into the same walkie-talkie. This information was superimposed video tape sound track, through the second walkie-talkie mounted near the camera's microphone.

The locations were video taped during several peak and off-peak periods, when weather was clear and the pavement surface dry. Table 4.2 shows the observed locations and date of video taping. Video camera location, reference points (point 1 and 2) as well as the approximate range of the camera's view at the observed locations are shown in Figures B.1 to B.8 in Appendix B.

Table 4.2 List of the Selected Locations and Observation Periods

Location	Video taping date and weather condition
23 Avenue	- Wed. July 15, 1992 (PM peak) (15:58 - 17:08) clear, windy - Thur. July 16, 1992 (PM peak) (15:21 -17:07) cloudy
99 Street	- Wed. June 24, 1992 (PM peak) (16:12 - 17:45) sunny - Wed. Aug. 5, 1992 (PM peak) (15:51 -17:24) sunny
Keillor Road	- Monday, June 22, 1992 (PM peak) (16:09 - 17:42) warm, sunny - Tues. July 7, 1992 (AM off-peak) (10:02 - 11:00) sunny - Monday Aug. 10, 1992 (PM off-peak) (14:24 - 15:28) sunny - Monday Aug. 10, 1992 (PM peak) (15:28 - 16:47) sunny
West Edmonton Mall	- Tues. July 21, 1992 (PM peak) (16:07 - 17:39) cloudy - Thur. July 23, 1992 (PM peak) (15:43 - 17:17) cloudy - Thur. Aug. 6, 1992 (PM off-peak) (14:44 - 15:31) hot, sunny - Thur. Aug. 6, 1992 (PM peak) (15:31 - 17:43) hot, sunny - Thur. Aug. 13, 1992 (AM off-peak) (11:04 - 12:37) sunny
Stony Plain	- Tues. Aug. 11, 1992 (PM peak) (16:43 - 18:17) sunny, clear

Advantage of Video Taping

1- Provide a permanent record of traffic movements at certain intersections so reference may be made back to the original record as often as required.
2- Video taping offers continuous viewing of the recorded data throughout the observation period.
3- The camera's microphone can be used to add synchronized information to the visual record.
4- The correct functioning of the equipment can be checked on site through tests that can be run before and during the recording.

Data Entry Phase

In this phase, data was entered using IBM 286 personal computer while observing the video tape.

Required Equipment and Manpower

1- 2 people
2- TV monitor
3- Video Cassette Recorder (VCR)
4- Personal computer
5- Data input software

A VCR (Panasonic AG-1200) was used to play back the video recording tapes in the office at normal speed. A TV monitor (Panasonic) was used to view the recorded picture. A software "TDIP" (Boesen et al 1991) was used to allow for the real time data entry into the computer while observing the videotape of intersection operation.

TDIP Description

TDIP (Traffic Data Input Program) is a program developed at the University of Idaho, Moscow, USA. The program can be used with an IBM-compatible personal computer to enter traffic data in the office, while observing a video tape of traffic flow at an intersection. The program can be used to collect four different types of data:

1- Approach volume, by recording the arrival or departure times of vehicles,
2- Turning movement, by recording the departure times of vehicles by approach and turning movements,
3- Delay data, used to calculate the total delay time by recording the times when vehicle enters the queue and when it leaves the queue,
4- Gap and delay data, used to calculate the time a vehicle is delayed in queue and the time the vehicle is delayed waiting for a gap in traffic once it becomes first in queue. This can be done by recording the times when a vehicle enters the queue, becomes first vehicle in queue and when it exits the queue.

The program can store the data in two different files; a Master File and a Summary File. The Master File is a record of the times each vehicle enters, leaves a queue and enters the intersection. Time is stored in a decimal 24-hour clock format that ranges between zero at the beginning of the day (12:00 midnight) to 1.0 at the end of the day (12:00 midnight, 24 hours later). The summary file is a summary of vehicles' volume or delays in 1-minute, 5-minute, and 15-minute time increments. The program can convert these files into worksheet form for later analysis.

Data Entry Process

Data was entered in two stages using TDIP program. The first stage concerns the left turning traffic and the second stage, the through traffic.

Data Entry For Left Turning Traffic

The following information was required for each driver: waiting time in the queue, waiting time in front of the queue, gender, age group, presence of passengers in the vehicle and vehicle's acceleration capability. The process was as follows:

1- Choose gap and delay type of data entry from program menu,
2- Play the video tape and choose a suitable beginning time for the data entry. (The time was chosen when there were no left turning vehicles in the queue),
3- Enter into the computer the identified beginning and ending times of the observation period (actual time from the video tape)

4- Start playing the video tape again and synchronize the computer clock with the chosen beginning time on the video tape. This was done by pressing the start key of the program when the time on the TV screen turned to the pre-identified beginning time,

5- Press 1 when a vehicle enters the queue;
press 2 when a vehicle becomes first vehicle in queue
press 3 when a vehicle crosses the conflict point.

6- Save the data in a Master File under selected name.

7- Convert Master File into worksheet format.

8- Print worksheet file using any spreadsheet program.

9- Replay the same videotape and start, at the same beginning point, recording manually for each vehicle driver gender, age group, presence of passengers, and vehicle's acceleration capability group.

10- Enter the information from step 8 into the worksheet in binary form as following:

- *Gender of driver* = 1 if male driver,
= 0 if female driver.

-*Age group* entered in 2 columns[1]:

a- Young driver = 1 if young,
= 0 otherwise.

b- Middle age driver = 1 if Average,
= 0 otherwise.

If both columns were zero, this indicates an old driver.

-*Presence of passengers* = 1 if there are passengers
= 0 if no passengers

[1]For a variable that was divided into n groups, only (n-1) variable groups could be included in the data file for model estimation. For example, Age of driver was divided into three groups: young, middle age, and old, therefore only 2 groups were allowed to be in the model

-Acceleration capability entered in 2 columns:

a- Low acceleration = 1 if low
= 0 otherwise

b- Average acceleration = 1 if Average
= 0 otherwise

If both columns were zero, this indicates a high acceleration capability vehicle.

Data Entry For Through Traffic

The following information was required: the arrival times of each main stream through vehicle at the two reference points as well as type of vehicle. This information can be obtained using delay data type of entry in TDIP program. The process was as follows:

1- Choose delay type of data entry from program menu,
2- Set the beginning and ending times of the observation period (actual time of video taping),
3- Start playing the video tape and synchronize the computer clock with the time on the video tape as used for the data entry for left turning traffic,
4- Press 1 when a vehicle arrives at first point,
press 2 when the vehicle arrives at second point.
5- Record manually type of through vehicle other than passenger car, and its number.
6- Save the data in a Master File under selected name.
7- Convert Master File into worksheet format.
8- Print worksheet file using any spread sheet program.
9- Enter the information from step 5 into the worksheet in a binary form as follows:

-Type of opposing vehicle entered in 2 columns:

a- Passenger car = 1 if passenger vehicle
= 0 otherwise

b- Truck or Bus = 1 if truck or bus
= 0 otherwise

c- Motorcycle = 1 if motorcycle
= 0 otherwise

If the three columns were zero, this means it was a bicycle

The first reference point (point 1) was chosen as an approximate center of the conflict area of left turning vehicles with the through traffic. This point was marked on the TV screen using adhesive tape. The second reference point (point 2) was chosen as the point of intersecting through-approach centerline and the line of sight between camera lens and a pre identified fixed object on the site, such as a lamp post, power pole or sign post. This point was identified on the TV screen as the point where vehicles pass by the fixed point. The location of the chosen fixed object was measured on site using a measuring tape. The distance between the two reference points (point 1 and point 2) was measured later from an exact intersection geometric layout. The two lines of sight from camera lens to point 1 and to point 2 are shown in Figures B.1 to B.8 in Appendix B.

It was very difficult to enter data for through traffic by lane, due to the difficulty of identifying the lane in which vehicles were moving. Therefore, it was decided to enter the data as if vehicles were moving in the center of the approach, which would be expected to affect the accuracy of speed estimation.

4.3.3 Practical Experience From Data Collection

a. Due to the difficulty of identifying drivers and vehicles' characteristics from viewing the video tapes, two walkie-talkies were used. One walkie-talkie was used for transmitting the information observed while standing near the intersection to the other walkie-talkie mounted near camera's microphone.

b. The two observers standing near the intersection had to share one walkie-talkie for dictation. Using two walkie-talkies at the same time caused a radio wave interference and sound could not be transmitted through the walkie-talkie mounted near the camera's microphone.

c. Because the words male and female were not distinguishable, it was decided to use the words boy and girl instead, for easier recognition. For recording the acceleration capability category for each turning vehicle, the words fast, average, slow were used because they were easier to recall than using the words high, average, and low acceleration capability.

d. The video camera would stop operating if anyone talked into a walkie-talkie near the camera. This might have been due to video interference.

e. It was more convenient to use a car battery or portable generator than a battery pack, which has a limited charge time.

4.3.4 Special Observations at the Studied Location

a. By research design, all of the chosen intersections had virtually no pedestrian activity that would interfere with the left turning movement. Therefore, the effect of pedestrians was not studied and the few periods where there was pedestrian interference to the through traffic were eliminated from the data set.

b. Some drivers in the left turning lane changed their minds and went straight through or made U-turns. The data for those drivers were entered first and later removed without having any effect on the data of the following vehicles.

c. At 23 Avenue and 110 Street, some left turning drivers appeared relatively aggressive forcing the main stream drivers to slow down.

4.3.5 List of Worksheet Data Files

Output file names from TDIP program are listed in Table 4.3. The first two letters of the file name are location identification (usually the first two letters of the intersection name). The third letter indicates the type of movement (L for left turn movement, and T for through movement). The forth letter indicates whether data were collected in the peak hours "P" or in the off-peak hours "O". The fifth and sixth letters indicate the day of the month when data were collected. All file names had the extension WK1

Table 4.3 List of Worksheet Data File

Location	Video taping Date	For Left turning	For through movement
23 Avenue	- July 15, 1992 (PM peak)	23LP15.WK1	23TP15.WK1
	- July 16, 1992 (PM peak)	23LP16.WK1	23TP16.WK1
99 Street	- June 24, 1992 (PM peak)	99LP24.WK1	99TP24.WK1
	- Aug. 5, 1992 (PM peak)	99LP5.WK1	99TP5.WK1
Keillor Road	- June 22, 1992 (PM peak)	KELP22.WK1	KETP22.WK1
	- July 7, 1992 (AM off-peak)	KELO7.WK1	KETO7.WK1
	- Aug. 10, 1992 (PM off-peak)	KELO10.WK1	KETO10.W1
	- Aug. 10, 1992 (PM peak)	KELP10.WK1	KETP10.WK1
West	- July 21, 1992 (PM peak)	WELP21.WK1	WETP21.W1
Edmonton	- July 23, 1992 (PM peak)	WELP23.WK1	WETP23.W1
Mall	- Aug. 6, 1992 (PM off-peak)	WELO6.WK1	WETO6.WK1
	- Aug. 6, 1992 (PM peak)	WELP6.WK1	WETP6.WK1
	- Aug. 13, 1992 (AM off-peak)	WELO13.WK1	WETO13.W1
Stony Plain	- Aug. 11, 1992 (PM peak)	SPLP11.WK1	SPTP11.WK1

4.4 SUMMARY

Data used for this study were gathered for five unsignalized T-intersections located in the City of Edmonton and its environs. A video taping technique was employed at the selected intersections during several peak and off-peak periods.

Total time of raw video taping at all locations was approximately 25 hours. Only 20 hours of complete data could be used which included 3,436 observed left turning vehicles accepting or rejecting gaps between 13,070 main stream through vehicles.

A summary of the locations, video taping dates, duration, number of observed left turning and through drivers is given in Table 4.4.

Data were entered using special traffic data input software "TDIP" (Boesen et al 1991) by pressing keys on a personal computer to identify events as they occur while watching the video tape. These events and the time at which they occurred formed a basis for subsequent analyses.

Table 4.4 Summary of Video Taping duration and Numbers of observed left Turning drivers and through Vehicles

Location	Video taping Date	Duration of video taping hour, min.	No. of left turning vehicles	No. of Through vehicles
23 Avenue	- July 15, 1992 (PM peak)	1 10	122	616
	- July 16, 1992 (PM peak)	1 46	203	1016
99 Street	- June 24, 1992 (PM peak)	1 33	189	1809
	- Aug. 5, 1992 (PM peak)	1 32	148	1387
Keillor Road	- June 22, 1992 (PM peak)	1 32	374	1630
	- July 7, 1992 (AM off-peak)	0 58	259	469
	- Aug. 10, 1992 (PM off-peak)	1 3	279	653
	- Aug. 10, 1992 (PM peak)	1 19	353	1135
West Edmonton Mall	- July 21, 1992 (PM peak)	1 32	208	774
	- July 23, 1992 (PM peak)	1 33	188	913
	- Aug. 6, 1992 (PM off-peak)	0 47	105	406
	- Aug. 6, 1992 (PM peak)	2 11	199	892
	- Aug. 13, 1992 (AM off-peak)	1 32	207	601
Stony Plain	- Aug. 11, 1992 (PM peak)	1 32	600	766
Total		20 0	3,434	13,067

CHAPTER 5

DATA ANALYSIS

5.0 INTRODUCTION

Following the videotaping, the required events and information for the through and left turning movements were entered separately into a personal computer using the data input program (TDIP 1991) as described in Chapter 4. The entered data were analyzed to determine the gap situations involved and the chosen alternative. For each gap situation, gap attributes and driver characteristics were calculated as described, in Section 5.1.

This chapter consists of two parts. Part 1 describes procedures for calculating the variables required for model estimation. Part 2 presents a description of the collected data.

5.1 CALCULATION OF VARIABLES REQUIRED FOR MODELLING

This section describes how the variables required for the modelling phase were calculated from the recorded events and coded in the formats required by the logit estimation program (NTELOGIT 1992).

The outputs from the data entry phase are two files for each observation period. The first file contains left turning vehicle data. It includes the following events in order:

Enter = Arrival time at the end of the queue,
Waiting = Arrival time at the head of the queue,
Leave = Arrival time at the conflict point.

It also includes gender, age group of the drivers, presence of passengers in the turning vehicles and acceleration capability of the turning vehicles. An example of left turning traffic data is given in Table 5.1.

Table 5.1 Example of Left-Turning Vehicle Data

Location : 99 Street
Date : June 24, 1992
Survey time : PM Peak

Vehicle number *	Enter **	Waiting **	Leave **	Gender ***	Age ***		Presence of Passengers ***	Acceleration capability ***	
				M / F	Young	Middle	Yes / No	Low	Average
22	0.681374	0.681379	0.681409	1	0	1	0	1	0
23	0.681498	0.681501	0.681541	1	0	1	1	1	0
24	0.681718	0.681721	0.681734	1	1	0	0	0	0
25	0.681852	0.681856	0.682105	0	0	1	0	0	1
26	0.68188	0.68211	0.682133	1	0	0	0	0	1
27	0.68244	0.682444	0.682531	1	0	1	0	0	0
28	0.682477	0.682539	0.682658	0	1	0	1	0	1
29	0.682775	0.682778	0.6828	0	0	1	0	0	1
30	0.683756	0.68376	0.68385	1	0	1	0	0	1

* Vehicle numbers were entered in the spread sheet later (not an output of the data input program"TDIP")

** Times are in Fractions of a day, e.g., Time: 0.681374 = (0.681374 * 24) = 16.352976 h = 16:21:10.71

*** Variables that were divided into "n" categories. Only n-1 categories are allowed in the model. (e.g., variable "Age" has been divided into 3 categories: Young, Middle, Old so, 2 categories can be included as follows:

	Variable 1 (Young)	Variable 2 (Middle)
If Young	1	0
If Middle	0	1
If Old	0	0

The second file contains opposing through traffic data. It includes the arrival time at the conflict point (point 1) and at point 2, which was set at a fixed distance from point 1, as well as the type of vehicle. An example of through traffic data recorded for the same observation period as in Table 5.1, is shown in Table 5.2.

The output from the data entry phase showed that the data collected involved a total of 3,434 left turning vehicles accepting or rejecting gaps between 13,067 opposing through vehicles during periods of over than 20 hours.

5.1.1 Example of Variables Calculation

The following is an example of how the required variables were calculated for each gap situation faced by one of the left turning vehicles (vehicle number 27) from the previous output data files.

The following are the data for left turning vehicle number 27 taken from Table 5.1.

Vehicle number	Enter	Waiting	Leave
27	0.682440	0.682444	0.682531

Driver of vehicle number 27 was a male, of middle age, with no passengers. He was driving a high acceleration capability vehicle as shown in Table 5.1.

The following are the data for the opposing through vehicles passing through the intersection, while vehicle number 27 was waiting for a gap, taken from Table 5.2.

Vehicle number *	Arrival at Point 1 **	Arrival at Point 2 **	Type of opposing vehicles		
			Passenger car	Truck / Bus	Motorcycle
222	0.682437	0.682473	1	0	0
223	0.68247	0.682493	1	0	0
224	0.682503	0.682541	1	0	0
225	0.682606	0.682636	1	0	0

Table 5.2 Example of Through Vehicle Data

Location : 99 Street
Date : June 24, 1992
Survey time : PM Peak

Vehicle number *	Arrival at Point 1 **	Arrival at Point 2 **	Type of opposing vehicles		
			Passenger car	Truck / Bus	Motorcycle
218	0.682383	0.682422	1	0	0
219	0.682404	0.682438	1	0	0
220	0.682412	0.682441	1	0	0
221	0.682427	0.682458	1	0	0
222	0.682437	0.682473	1	0	0
223	0.68247	0.682493	1	0	0
224	0.682503	0.682541	1	0	0
225	0.682606	0.682636	1	0	0
226	0.682739	0.682769	1	0	0
227	0.68305	0.683073	1	0	0
228	0.68308	0.683109	1	0	0

* Vehicle number was entered by the researcher in the spread sheet later (not an out put of the data input program)

** Times are in Fractions of a day, e.g., Time: 0.682383 = (0.682383 • 24) = 16.377192 h = 16:22:63.15

Queue delay (Qdelay) = Waiting - Enter
= (0.682444 - 0.682440) *24*60*60 = 0.35 s

Comparison of waiting time for vehicle number 27 to arrival times of through vehicles at conflict point (point 1):

Arrival $1_{(222)}$ < Waiting < Arrival $1_{(223)}$[1]
0.682437 < 0.682444 < 0.682470

This means that left turning vehicle number 27 arrived at the top of the queue before through vehicle number 223 arrived at the conflict point.

For first gap faced:

No. of rejected gaps up to this one = 0

Front delay = 0 sec

Gap size #1 (Lag size) = Arrival $1_{(223)}$ - Waiting
Gap size #1= (0.682470 - 0.682444) *24*60*60 = 2.25 Sec

Speed of vehicle ending that gap = $Speed_{(223)}$ = Distance / (Arrival 2 - Arrival 1)
= 38.5 / [(.682493 - .682470) *24*1000] = 70 Km/h

Comparison of arrival time of the left turning vehicle at conflict point (Leave) to the arrival time of through vehicle number 223 at the same point to identify whether this gap was accepted or rejected.

0.682531 > 0.682470
Leave > Arrival $1_{(223)}$

---

[1]Arrival $1_{(223)}$ means the arrival of through vehicle number 223 at point 1 (conflict point).

This means that; this gap was rejected because arrival time at point 1 for minor stream vehicle is greater than the arrival time of major stream vehicle ending that gap

For second gap faced:

No. of rejected gaps up to this one = 1

Front delay = Arrival $1_{(223)}$ - Waiting
=(0.682470 - 0.682444) *24*60*60 = 2.25 Sec

Gap size #2 = Arrival $1_{(224)}$ -Arrival $1_{(223)}$
= (0.682503 - 0.682470) *24*60*60 = 2.85 Sec.

Speed of vehicle ending that gap = $Speed_{(224)}$= Distance / (Arrival 2 - Arrival 1)
= 38.5 / [(.682541 - .682503) *24*1000] = 42 km/h

This gap was rejected because: Leave > Arrival $1_{(224)}$
0.682531 > 0.682503

For third gap faced:

No. of rejected gaps up to this one = 2

Front delay = Arrival $1_{(224)}$ - Waiting
=(0.682503 - 0.682444) *24*60*60 = 5.10 Sec

Gap size #3 = (0.682606 - 0.682503)*24*60*60 = 8.90 sec

$Speed_{(225)}$ = 38.5 / [(.682636 - .682606) *24*1000] = 53 km/h

This gap was accepted because: Leave < Arrival $1_{(225)}$
(0.682531 < 0.682606)

$$Microscopic\ flow\ rate = \frac{\text{Number of opposing vehicles}}{\text{Arrival } 1_{(225)} - \text{waiting}}$$

$$= 3 / [(0.682606 - 0.682444) * 24 * 60] = 12.86 \text{ veh/min}$$

The summary of the previous calculations for vehicle number 27, coded as required for model estimation program is shown in Table 5.3.

As shown in Table 5.3, for each left turning vehicle, some attributes are constant; such as driver's characteristics (gender and age), presence of passengers in the turning vehicle, queue delay, and flow rate of opposing traffic. Other attributes are different for each gap situation presented to the same driver; such as vehicle front delay, size of available gap, speed and type of vehicle ending the gap.

The same procedures would be repeated for each left turning vehicle. Therefore, a short program was written using Fortran language to perform these calculations for each one of the 3,434 left turning vehicles. The program source file is listed in Appendix C. The program also produces the output in the format required by the Logit estimation program that was described in Chapter 3. The outputs showed that left turning drivers faced a total of 8,652 gap situations at all the observed locations. An example of output calculation (input to logit estimation program) is given in Table C.1 in Appendix C.

All gap situations for each observation period were given special group identification numbers for later ease of identification, e.g., to distinguish peak-hour data from off-peak data or to identify data for certain observation period. Group identification numbers for the observation periods are shown in Table C.2 in Appendix C.

Table 5.3 Sumary of Gap Attributes and Driver Characteristics for Left Turning Vehicle Number 27 in Format Required for Logit Estimation Program

Group No.	Alt. No.	Choice freq.	Gender	Age		Pass	Acc.		Delay		Time gap	Speed	Type			Flow	# Rej
			M/ F	Y	M	Yes/No	L	A	Qdelay	Fdelay			P	T/B	M		
1	1	0	1	0	1	0	0	0	0.35	0	2.25	70	1	0	0	12.86	0
1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	1	0	1	0	0	0	0.35	2.25	2.85	42	1	0	0	12.86	1
2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	1	1	0	1	0	0	0	0.35	5.10	8.90	53	1	0	0	12.86	2
3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5.2 ANALYSIS OF DATA

The output from the variables calculation program (Fortran program) was saved and set as a data base in a spreadsheet program for easier analysis of the data, and extraction of any required information. The data base included 8,652 gap situations (17,304 records). The following sections give an overview of drivers' characteristics and gap attributes included in this study, as estimated from the data base file.

5.2.1 Left Turning Traffic

Characteristics of the observed left turning traffic, i.e., gender and age of drivers, presence of passengers in turning vehicle and vehicle acceleration capabilities for each location are given in Table 5.4.

Each left turning driver faced one or more gap situation. Characteristics of left turning traffic involved in gap situations at each location are given in Table 5.5. The following is a summary description of these characteristics:

Drivers' gender

It is shown that although on average male drivers represented approximately 63 %, they were only involved in 60 % of the total observed gap situations. This means that on average a female driver faced more gap situations than a male driver (this also means that a female driver on average rejected a larger number of gaps before accepting a gap). The highest percentage of male drivers (69 %) was found to be at the 99 Street and 66 Avenue intersection. The lowest percentage of male drivers (60 %) was at the Fox Drive and Keillor Road intersection.

Table 5.4 Characteristics of Left-Turning Traffic at Each Location

Location	Gender		Age			Presence of passengers		Acceleration capability			Total
	M	F	Y	M	O	Yes	No	L	A	H	
23 Avenue	198	127	89	212	24	100	225	59	255	11	325
99 Street	231	106	61	258	18	84	253	96	222	19	337
Keillor Road	758	507	304	891	70	293	972	344	818	103	1265
West Edmonton Mall	603	304	244	623	40	372	535	342	496	69	907
Stony Plain	364	236	130	452	18	162	438	259	327	14	600
Total	2154	1280	828	2436	170	1011	2423	1100	2118	216	3434
%	62.7	37.3	24.1	70.9	5.0	29.4	70.6	32.0	61.7	6.3	100.0

Numbers represent total observations of each characteristic

Table 5.5 Number of Choice Situations Involving Each Characteristic of Left-Turning Traffic

Location	Gender		Age			Presence of Passengers		Acceleration Capability			Total
	M	F	Y	M	O	Yes	No	L	A	H	
23 Avenue	446	290	196	476	64	239	497	131	576	29	736
99 Street	1058	512	299	1165	106	416	1154	443	1082	45	1570
Keillor Rd.	1764	1431	677	2341	177	869	2326	849	2116	230	3195
West Edmonton Mall	1304	763	570	1402	95	882	1185	823	1117	127	2067
Stony Plain	623	461	220	822	42	282	802	439	628	17	1084
Total	5195	3457	1962	6206	484	2688	5964	2685	5519	448	8652
%	60.0	40.0	22.7	71.7	5.6	31.1	68.9	31.0	63.8	5.2	100.0

Drivers' age

On average 71 % of the drivers were middle age (neither young nor old). Young and old drivers represented about 24 % and 5 % respectively, but young drivers were only involved in 22.7 % the total gap situations. This means that on average young drivers rejected less gaps before accepting a gap.

Presence of passengers in the turning vehicle

On average, left turning vehicles that have passengers represent 30 % of the total observed turning vehicles. These vehicles were involved in 31 % of the observed gap situations. The West Edmonton Mall location had the highest percentage of vehicles with passengers (41 %). These vehicles were involved in 43 % of the observed gap situations, which indicated that drivers with passengers rejected more gaps than drivers without passengers. This location is a major shopping and entertainment center where people tend to go together. The location that had the lowest percentage of vehicles with passengers (23 %) was Keillor Road followed by 99 Street intersection (25 %).

Acceleration capability of turning vehicles

62 % of total left turning vehicles were classified as average acceleration capability vehicles compared to 32 % and 6 % respectively for low and high acceleration capability vehicles. Although high acceleration capability vehicles represented 6.3 % of total vehicles, they were only involved in 5 % of total gap situations. This indicated that on average, drivers of the high acceleration capability vehicles rejected less gaps than drivers of average and low acceleration capability vehicles. Only passenger vehicles were included in this research.

5.2.2 Opposing Through Traffic

The number and percentage of observed opposing vehicles in each category are given in Table 5.6. The number and percentage of choice situations involving each type of opposing vehicle are given in Table 5.7. It is shown from these tables that the majority of through vehicles were passenger cars that represented 96% of the total vehicles. Trucks and buses represented 3%, compared to 0.6% and 0.2% for motorcycles and bicycles respectively. Although bicycles represented 0.2% of total vehicles, they were involved in 0.3 % of total gap situations. Also trucks and buses represented 3.1%, but were involved in 3.7% of all choice situations.

5.2.3 Queue Delay

Frequency distributions of queue delay at the different study locations are shown in Figure 5.1. Figure 5.2 illustrates the cumulative distribution of queue delay. The minimum, maximum, and mean values of queue delay at each location are given in Table 5.9 in Section 5.2.8. The highest value of queue delay was found to be around 80 seconds at the intersection of Fox Drive and Keillor Road. The highest mean value of queue delay was found to be around 6 seconds at the Stony Plain intersection. More than 50 % of vehicles at all study locations had a queue delay of less than 1.5 seconds. More than 80 % of vehicles observed at the intersection of 23 Avenue and 110 Street had a queue delay less than 1.5 seconds, and no vehicles experienced queue delay more than 21 seconds.

Table 5.6 Classification of Opposing Through Traffic

Location	Type of Opposing Traffic				Total
	P	T/B	M	BI	
23 Avenue	1561	58	7	6	1632
99 Street	3060	97	32	7	3196
Keillor Rd.	3712	144	21	10	3887
West Edmonton Mall	3497	69	15	5	3586
Stony Plain	724	33	5	4	766
Total	12554	401	80	32	13067
%	96.1	3.1	0.6	0.2	100.0

Numbers represent total observation of each type of opposing vehicles

Table 5.7 Number of Gap Situations Involving Each Type of Opposing Vehicle

Location	Type of Opposing Traffic				Total
	P	T/B	M	BI	
23 Avenue	704	26	1	5	736
99 Street	1497	56	15	2	1570
Keillor Rd.	3026	135	20	14	3195
West Edmonton Mall	2004	50	11	2	2067
Stony Plain	1027	49	6	2	1084
Total	8258	316	53	25	8652
%	95.4	3.7	0.6	0.3	100.0

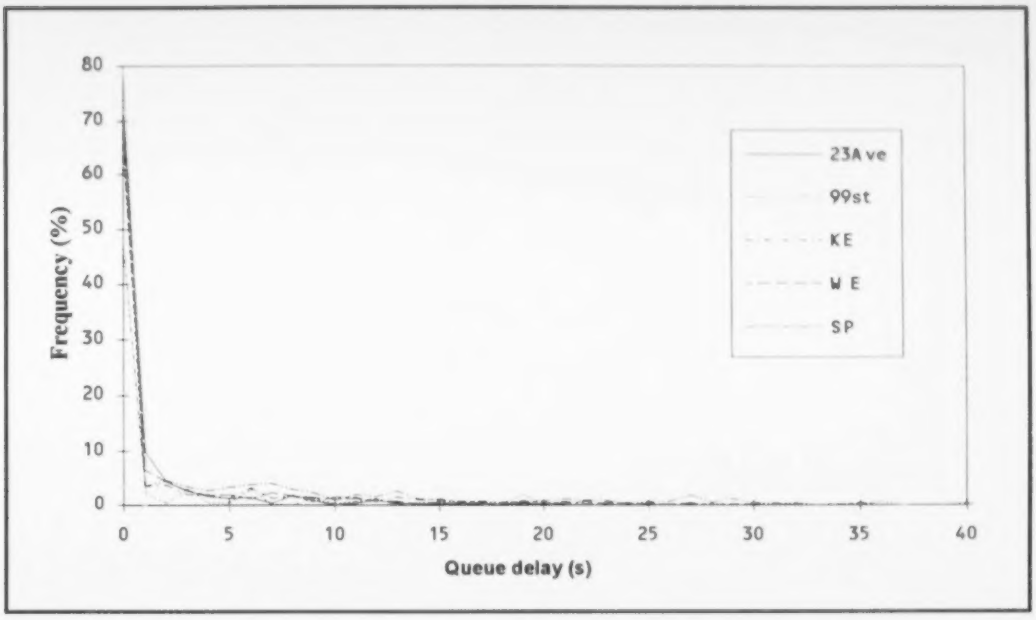

Figure 5.1 Distribution of Queue Delay at Different Study Locations

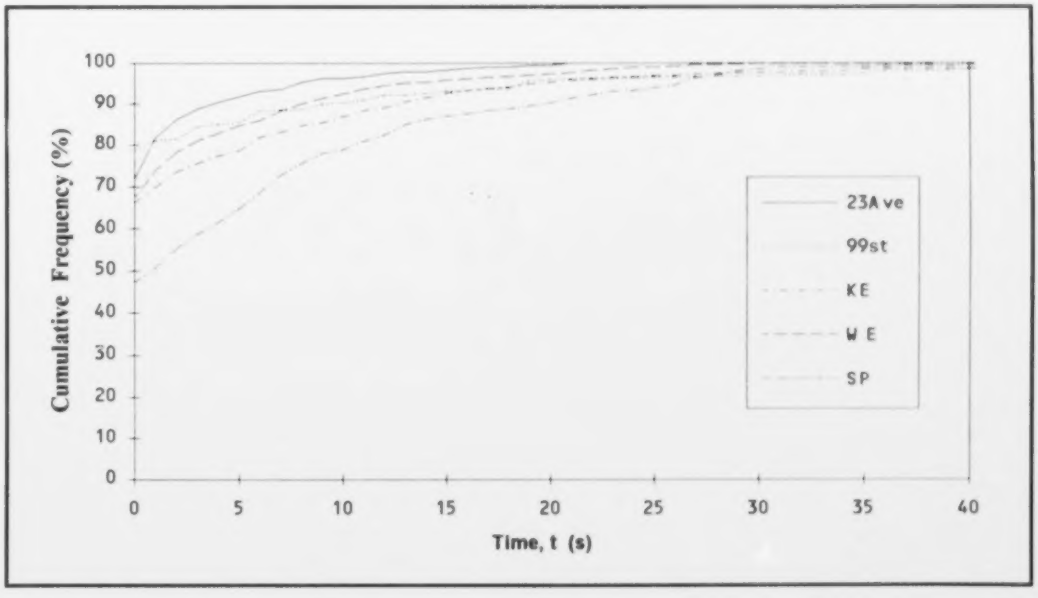

Figure 5.2 Distribution of Queue Delay Equal to or Less Than t at the Study Locations

5.2.4 Front Delay

Frequency distributions of front delay at the study locations are shown in Figure 5.3. The cumulative distribution of front delay is shown in Figure 5.4. The minimum, maximum, and mean values of front delay at each location are shown in Table 5.9 in Section 5.2.8. The highest value of front delay was approximately 70 seconds at the 99 Street location. The same intersection had the highest mean value of front delay, approximately 10 seconds. The Stony Plain intersection had the lowest mean value of front delay, approximately 3 seconds. At all locations, except the 99 street location, less than 2 % of gap situations involved front delay greater than 30 seconds. At the 99 Street location, approximately 8% of choices involved front delay greater than 30 seconds. At all locations, except at the 99 Street location, more than 45 % of choices involved front delay of less than 1.5 seconds.

Table 5.8 presents numbers and percentages of drivers experiencing different amount of front delay. Only 43 drivers (1.25%) experienced front delay greater than 30 seconds. T statistics (T-test) was used to test whether the observed drivers with front delay greater than 30 seconds (43 drivers) belong to the same population as the total observed sample (3434 drivers). The test proved that there is no difference between the two samples mean.

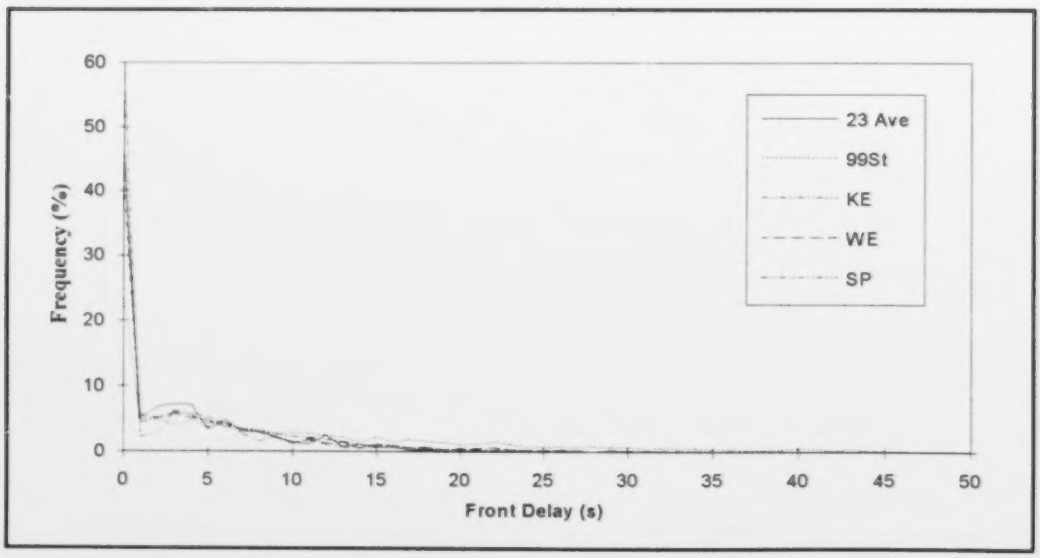

Figure 5.3 Distribution of Front Delay at Different Study Locations

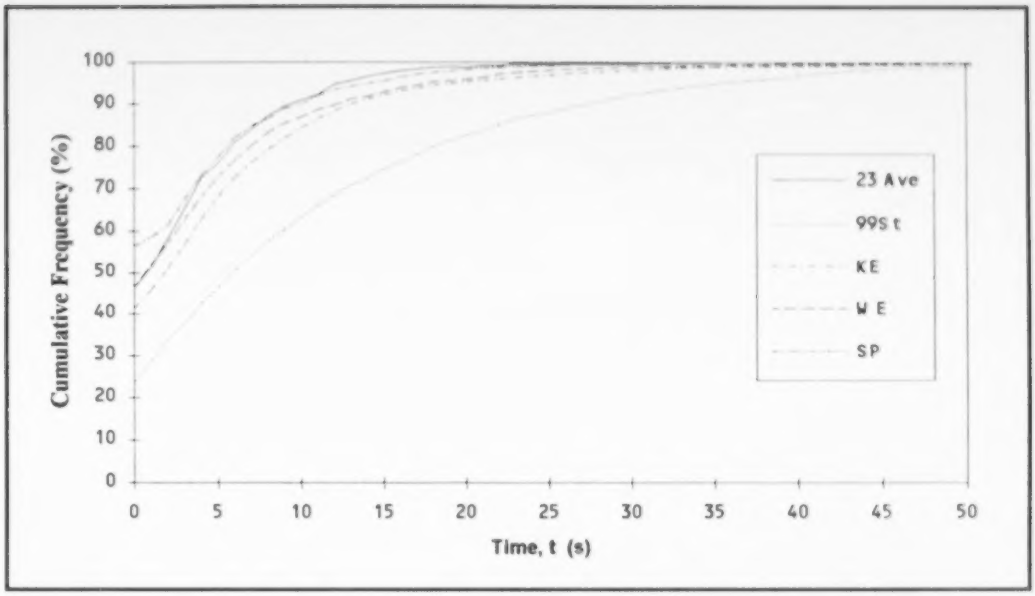

Figure 5.4 Distribution of Front Delay equal to or less than t, at Different Study Locations

Table 5.8 Numbers and Percentages of drivers experiencing Different Ranges of Front Delay

Fdelay (s)	Number of Drivers	Percentage of Drivers (%)
0 - 5	2615	76.15
5 - 10	434	12.64
10 - 15	194	5.65
15 - 20	89	2.59
20 - 25	38	1.11
25 - 30	21	0.61
> 30	43	1.25

5.2.5 Time Gap (Headway)

Frequency distributions of time gaps (headways) at study locations are shown in Figure 5.5. Figure 5.6 illustrates the cumulative distributions of gaps. The minimum, maximum, and mean values are given in Table 5.9 in section 5.2.8. Distribution of gaps varied greatly among locations. At the 99 Street location, more than 80 % of available gaps were less than 5 seconds, compared to 45 % at the Stony Plain location.

Gap distributions at the 23 Avenue and at the Stony Plain locations, were found to follow a negative exponential distribution. This indicates that the arrival of main street vehicles are random at those two locations. Several composite functions fitted to the other locations, showed some degree of non-randomness (platooning) due to the effect of the upstream traffic lights. This result indicated that the observed data covered all types of arrivals.

The lowest mean gap was found to be 3.85 seconds at the 99 Street location compared to 8.94 seconds at the Stony Plain location.

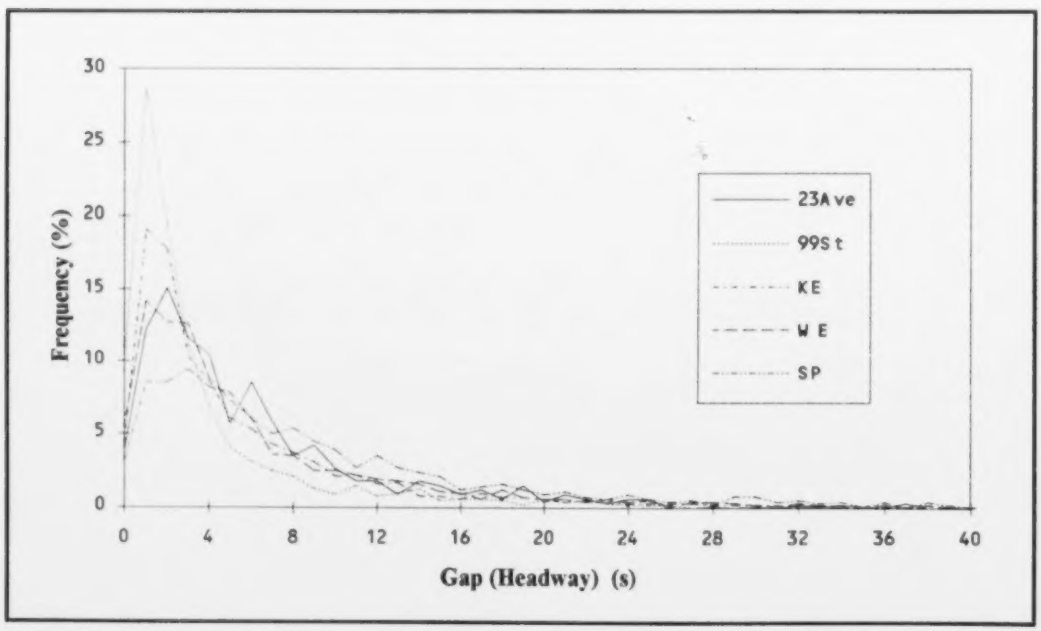

Figure 5.5 Time Gap (Headway) Distribution

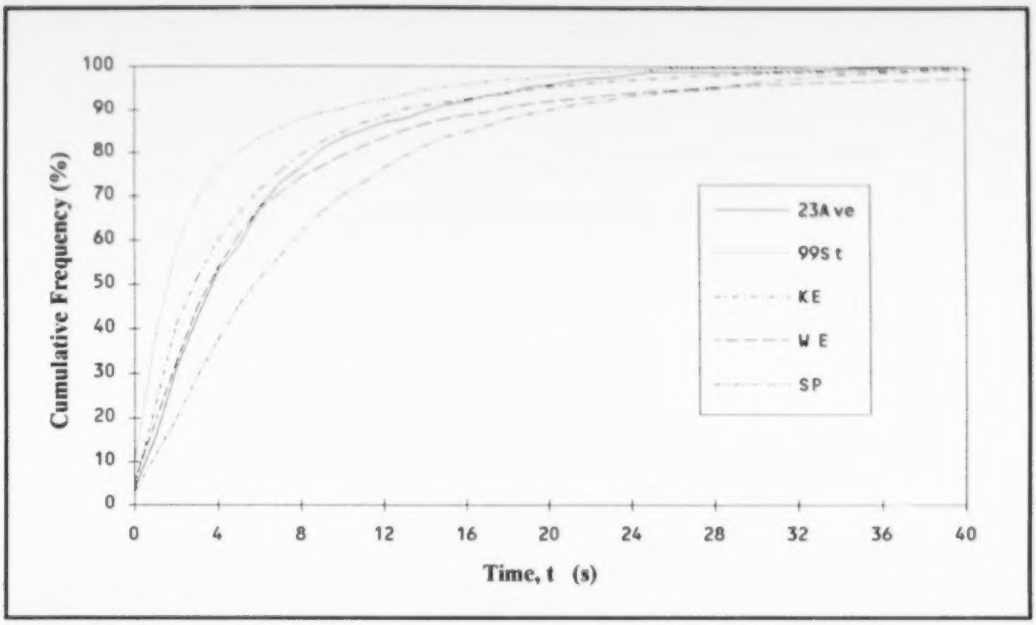

Figure 5.6 Distribution of Time Gap (Headway) Greater Than or Equal to t, at the Study Location

5.2.6 Speed of Opposing Vehicles

Frequency and cumulative distributions of speed at the study locations are shown in Figures 5.7 and 5.8. The minimum, maximum, and mean values at each location are shown in Table 5.9 in section 5.2.8.

The highest mean speed was approximately 90 km/h at the Stony Plain location, compared to 54 km/h at the 23 Avenue intersection. The distribution of speed at 99 Street, and West Edmonton Mall intersections are almost identical. Average speed at the 23 Avenue location was found to be slightly lower than the speed limit. However, average speed was higher than the speed limit at the 99 Street, West Edmonton Mall and Stony Plain locations. The Stony Plain intersection is located on Highway 16 where the highway speed limit is 100 km/h, but 80 km/h at the intersection location. At this location average speed was 10 km/h higher than the speed limit. At Keillor Road the average speed was exactly the same as the posted speed limit, due to the frequent speed enforcement at this location.

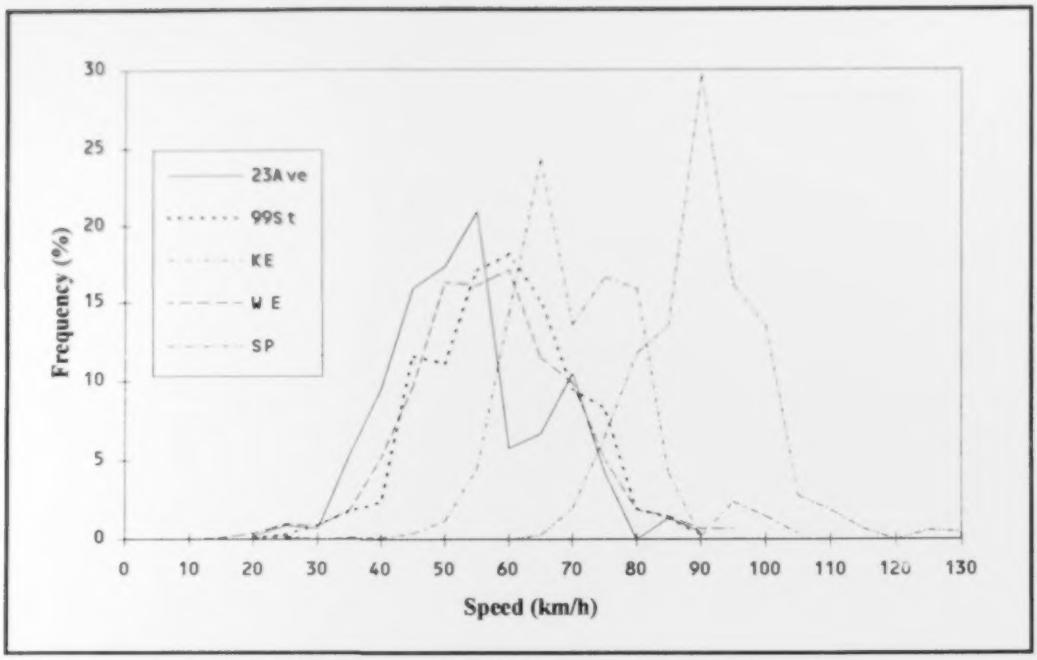

Figure 5.7 Speed Distribution at the Study Locations

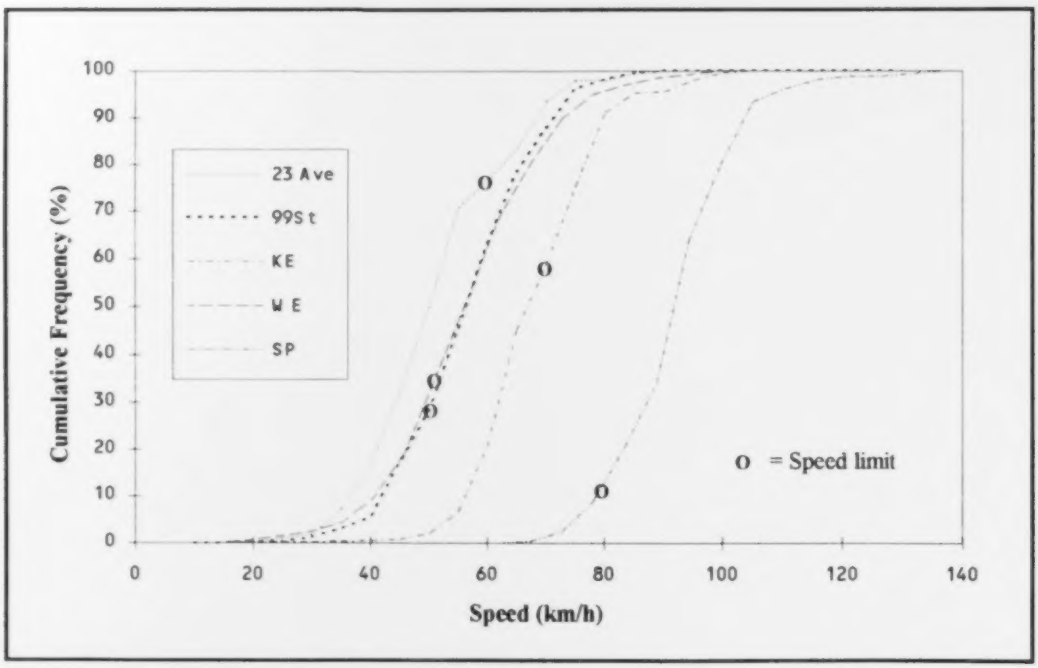

Figure 5.8 Cumulative Speed Distribution at the Study Locations

5.2.7 Number of Rejected Gaps

Frequency and cumulative distributions of the number of rejected gaps at the study locations, are shown in Figures 5.9 and 5.10. The minimum, maximum, and mean values at each location are given in Table 5.9 in section 5.2.8.

At the Stony Plain intersection, 90 % of gap situations involved rejection of only 3 gaps or less, compared to 48 % at 99 Street intersection. The maximum number of rejected gaps was 34 at 99 Street intersection, compared to 13 each at 23 Avenue, and Stony Plain intersections. The mean number of rejected gaps ranged from 1.1 gap at the Stony Plain location to 6.5 gaps at 99 Street intersection.

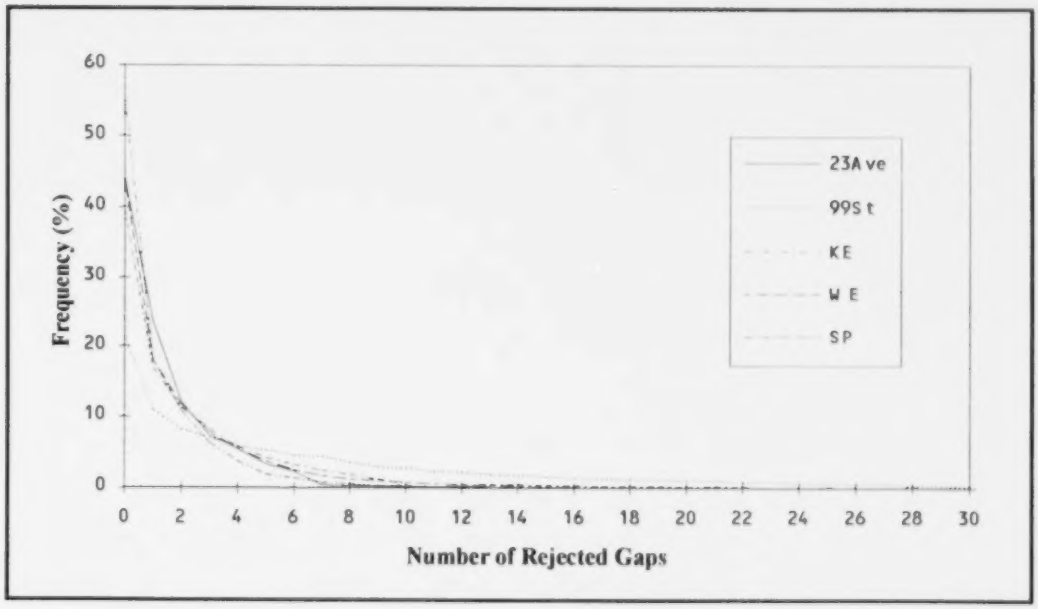

Figure 5.9 Distribution of Number of Rejected Gaps

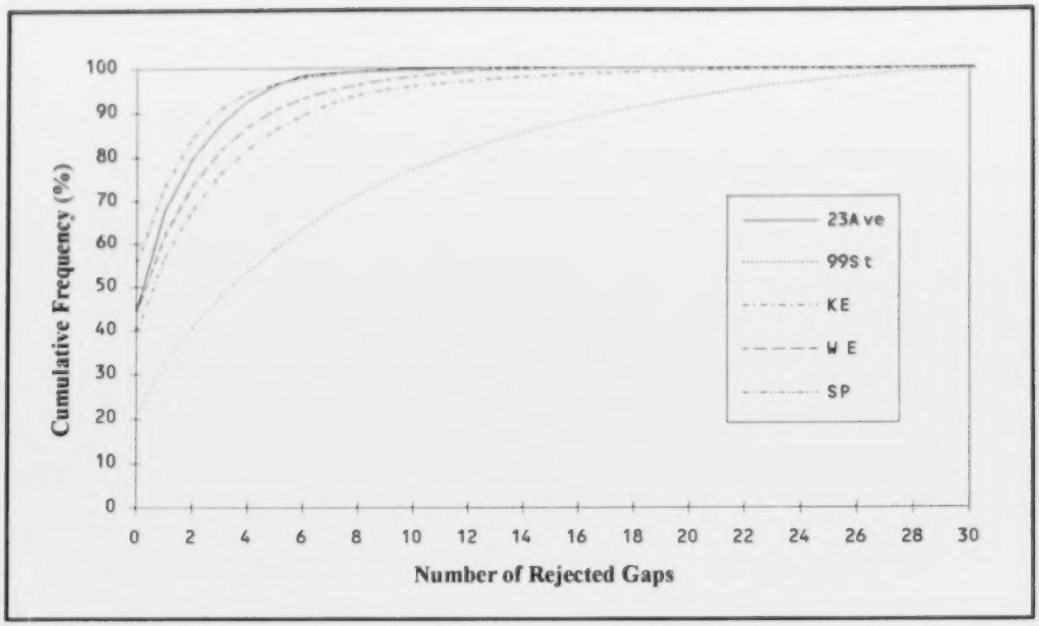

Figure 5.10 Cumulative Distribution of Number of Rejected Gaps

5.2.8 Variation of Variables

Table 5.9 lists the minimum, maximum, and mean values for each of the variables previously mentioned in sections 5.2.3 to 5.2.7

Table 5.9 Minimum, Maximum and Mean Values for Different Variables at Study Locations

Location		Queue delay	Front delay	Time gap	Speed	#Rej
23 Avenue	Min	0	0	0	22	0
	Max	20.8	36.46	39.57	90	13
	Mean	1.49	3.32	6.22	53.83	1.37
99 Street	Min	0	0	0	19	0
	Max	51.24	68.69	32.57	89	34
	Mean	3.05	10.36	3.85	58.82	6.43
Keillor Road	Min	0	0	0	21	0
	Max	79.92	57.54	64.8	107	32
	Mean	3.9	5.03	5.82	70.14	2.45
West Edmonton Mall	Min	0	0	0	8	0
	Max	49.16	63.5	90.29	97	16
	Mean	2.52	4.23	7.58	57.32	1.85
Stony Plain	Min	0	0	0	23	0
	Max	53.31	31.62	53.05	129	13
	Mean	5.95	3.22	8.94	90.2	1.11

5.2.9 Gap Acceptance

Frequency and cumulative frequency distributions of gap acceptance (as a percentage of total number of accepted gaps) at study locations, are given in Figures 5.11, and 5.12.

The minimum accepted time gap, which was exceptionally low, was found to be 1.04 seconds at the West Edmonton Mall location followed by 1.38 seconds at the 99 Street location.

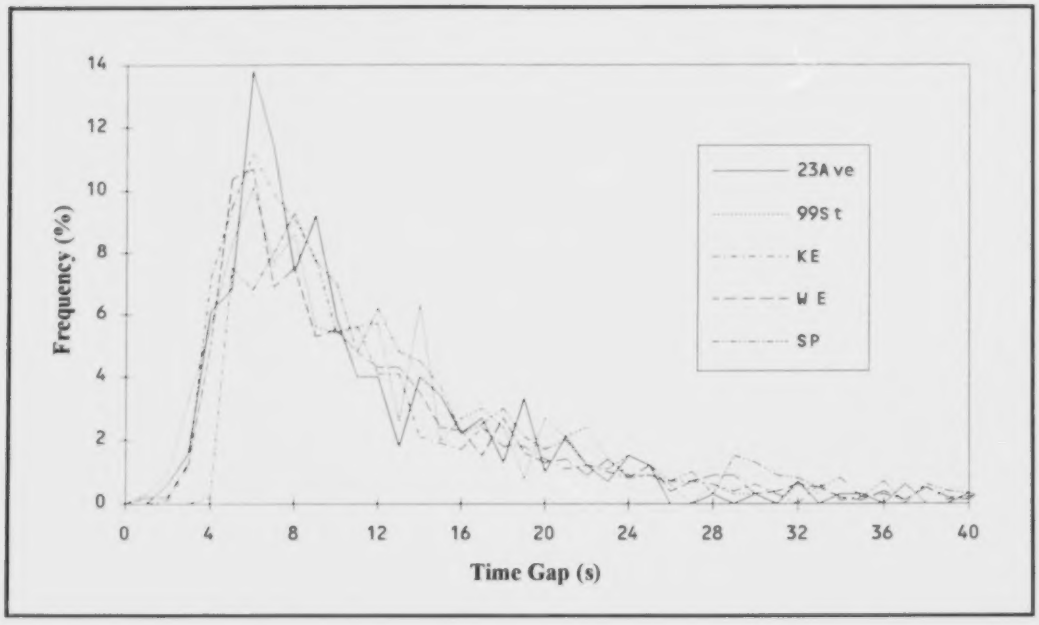

Figure 5.11 Gap Acceptance Distribution at Study Locations

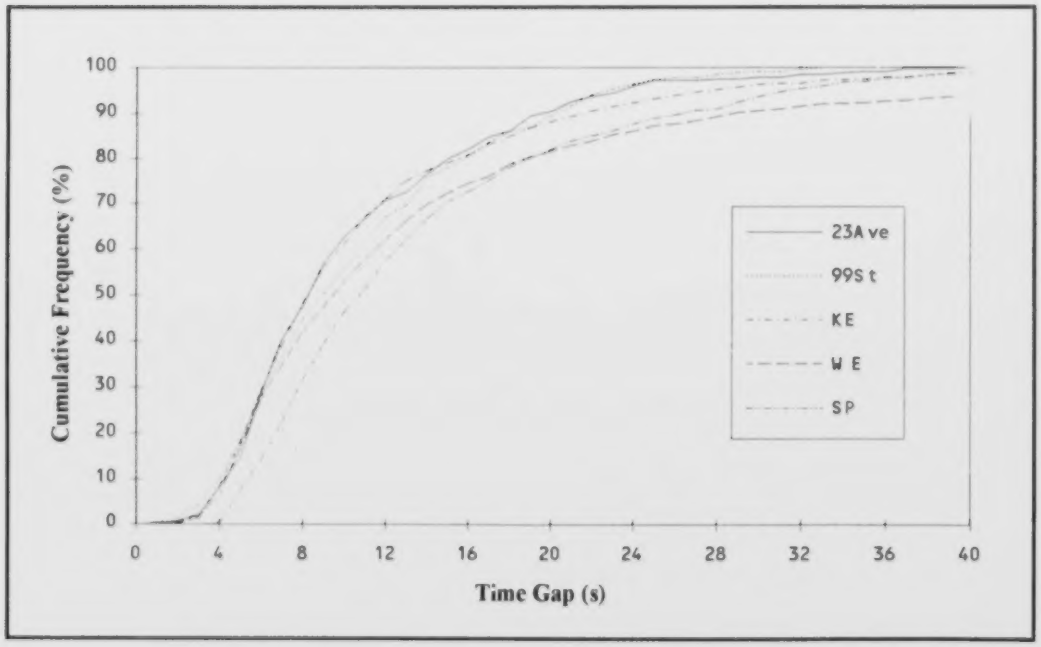

Figure 5.12 Cumulative Distribution of Gap Acceptance at Study Locations

Comparison of Gap and Lag Acceptance

Figure 5.13 illustrates the cumulative frequency distribution of the observed lags and gaps accepted by drivers. The lag acceptance curve represents distribution of gaps accepted by drivers who did not stop at the intersection, and accepted the first available gap (with no front delay). The gap acceptance curve represents distribution of gaps accepted by drivers who rejected the first available gap (lag), stopped at the intersection, and accepted a subsequent gap (with front delay). The two distributions are similar. A small percentage of drivers who did not stop (1.1%) accepted very short gaps (less than 3 seconds).

Number of accepted lags = 1458 (drivers who did not stop and accepted first available gap, with no front delay)
Number of accepted gaps = 1976 (drivers who rejected the lag and stopped, with front delay)

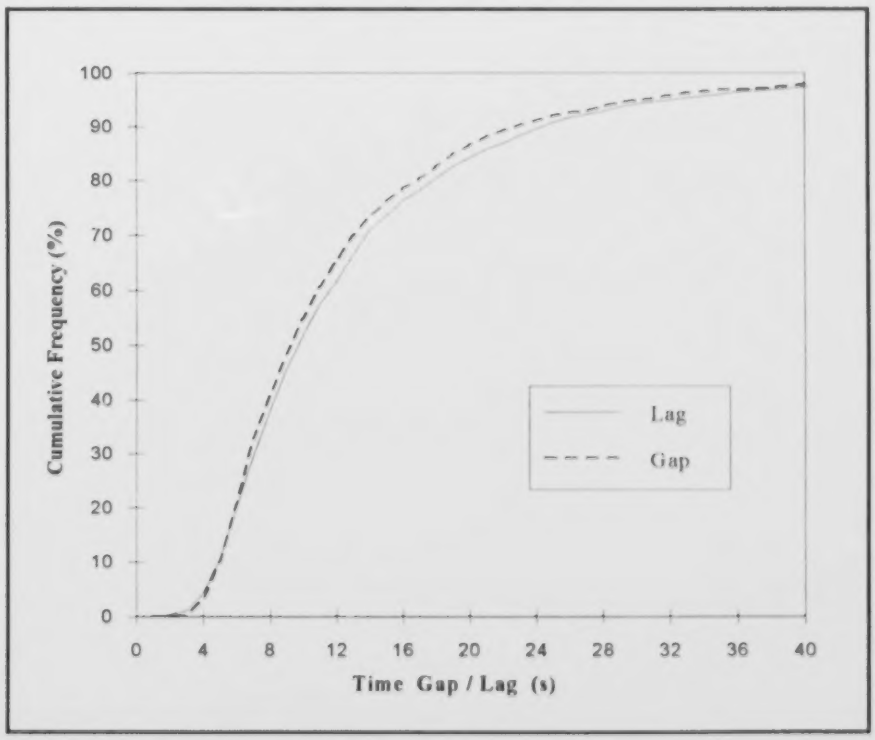

Figure 5.13 Comparison of Lag and Gap Acceptance Distributions

Comparison of the Accepted Gaps With Different Range of Front Delay

The frequency distributions of the accepted gaps by drivers with different ranges of front delay are shown in Figure 5.14. The gap acceptance distributions for drivers with front delays between 0- 15 seconds and 15 to 30 seconds are almost identical (with the exception of those who did not stop). Gaps around 6.0 to 7.0 seconds have the highest probability of acceptance. The distribution of gap acceptance for drivers with front delay greater than 30 seconds is different in that no drivers accepted gaps less than 4 seconds. Gaps around 4.0 to 5.0 seconds have the highest probability of acceptance. The figure also shows that the percentage of drivers with front delay greater than 30 seconds who accept a gap shorter than 5 seconds, is higher than that for drivers with front delay less than 30 seconds.

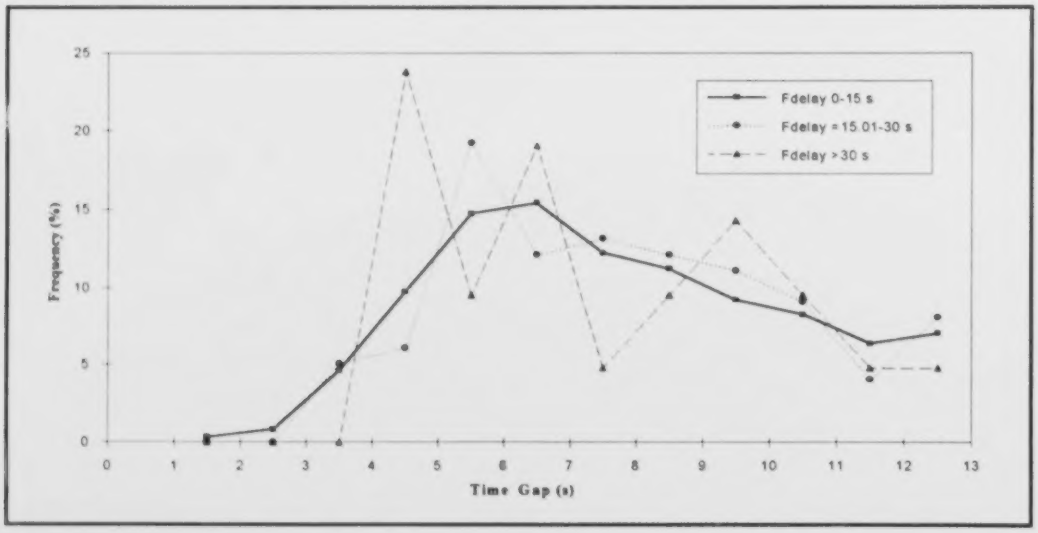

Figure 5.14 Distribution of Gaps Accepted by Drivers With Different Ranges of Front Delay

The average size of the accepted gap, for the situations included in the model estimations as described in Chapter 6, was found to be 7.7, 7.8, and 7.5 seconds respectively, for front delay between 0 to 15, 15 to 30, and greater than 30 seconds.

Figure 5.15 shows the average size of gaps accepted by drivers incurring different amounts of front delay (for all drivers, and for drivers included in the model). The figure indicates that drivers with front delay greater than 30 seconds, accepted on average shorter gaps, than drivers with front delay less than 30 seconds. For the latter, the average size of accepted gaps increases slightly with increasing front delay. For front delay greater than 30 seconds, the average size of the accepted gap decreases with increasing front delay.

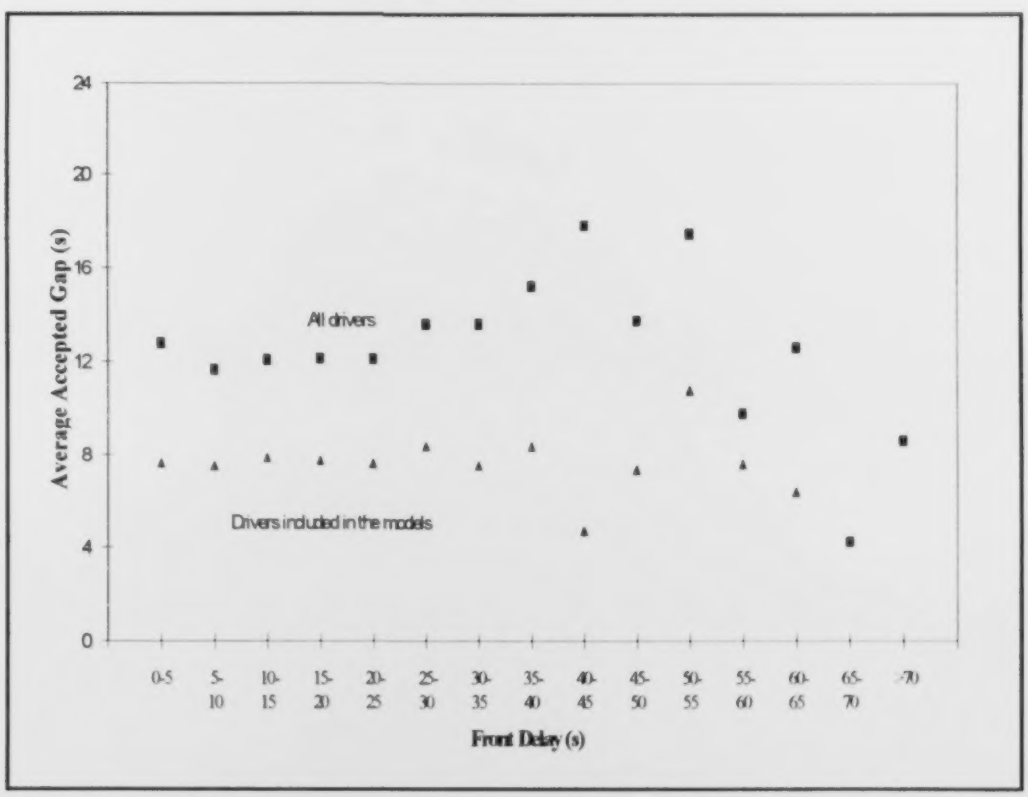

Figure 5.15 Effect of Front Delay on Size of Accepted Gap

Drivers Who Accepted Gaps Shorter Than Gaps They Previously Rejected

When examining the data, it was found that 58 drivers accepted gaps shorter than one or more gaps they had previously rejected. The average number of previously rejected gaps, which are longer than that accepted, for different values of front delay, are shown in Figure 5.16. This number is approximately 1.0 for front delay less than 30 seconds and 3.0 for front delay greater than 30 seconds.

The average size of the accepted gap for different values of front delay is shown in Figure 5.17 for the following drivers categories:

1- Drivers who accepted gaps longer than those they previously rejected (waited for a longer gap),

2- Drivers who waited for a longer gap and included in the models (Tgap <=13 s)

3- Drivers who accepted gaps shorter than those they previously rejected,

4- All observed drivers.

The number of drivers in each front delay range are shown in Table 5.10. 5.2% of those drivers, who accepted gaps shorter than previously rejected, incurred front delay greater than 30 seconds compared to 2.86% for drivers who waited for a longer gap and 1.25% for the total observed drivers.

The distribution of gaps accepted by drivers who accepted a gap shorter than a previously rejected gap, and for drivers who waited for a longer gap are presented in Figure 5.18. The distributions indicate that 57% of drivers who accepted a gap shorter than previously rejected, accept one equal to or less than 5 seconds, compared to only 8% of all drivers who waited for a longer gap (12% for those drivers who waited for a longer gap and are included in the models).

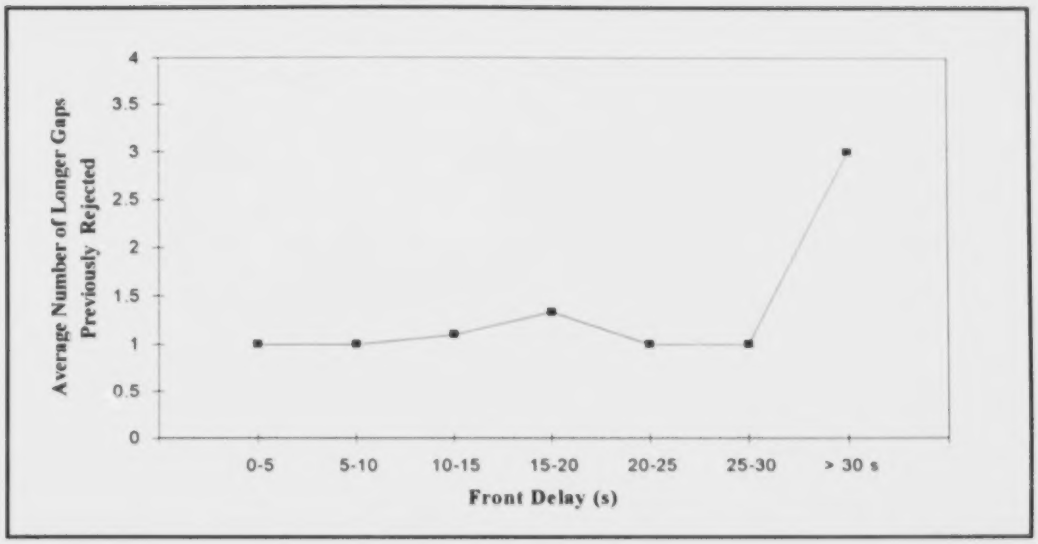

Figure 5.16 Effect of Front Delay on Average Number of Longer Gaps previously Rejected

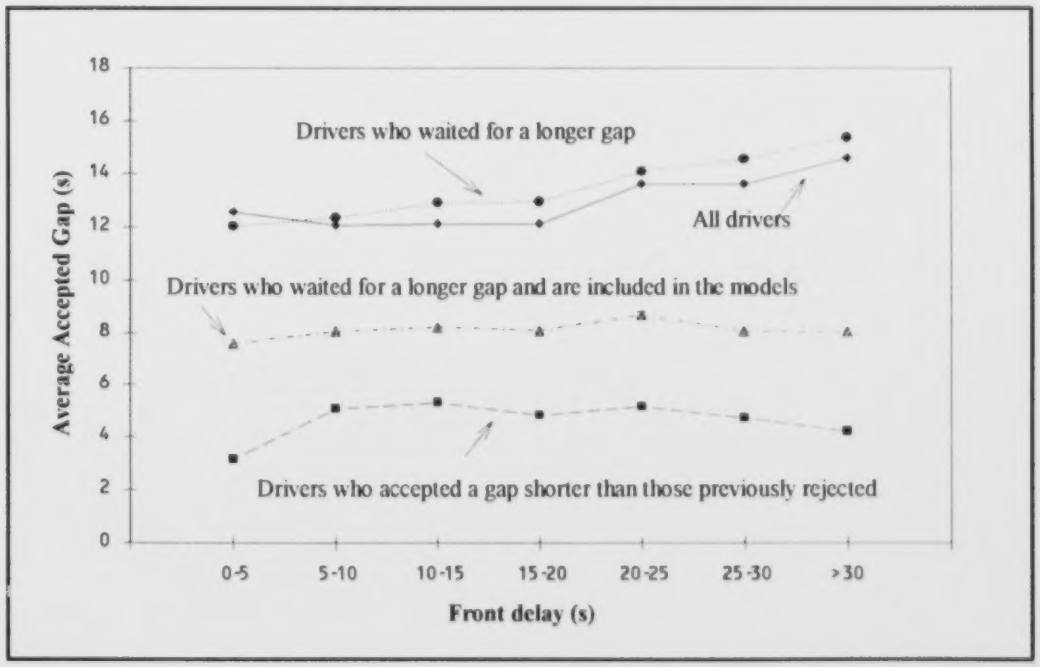

Figure 5.17 Average Size of Gap Accepted by Different Categories of Drivers at Different Values of Front Delay

Table 5.10 Number of Drivers Incurring Different Values of Front Delay

Number of Drivers	Front Delay (s)						
	0-5	5-10	10-15	15-20	20-25	25-30	>30
Who accepted a lag	1976						
Who waited for a longer gap (included in the models)	633 (447)	418 (293)	174 (114)	80 (56)	36 (22)	19 (11)	40 (18)
Who accepted a gap shorter than previously rejected	6	16	20	9	2	2	3
Total	2615	434	194	89	38	21	43

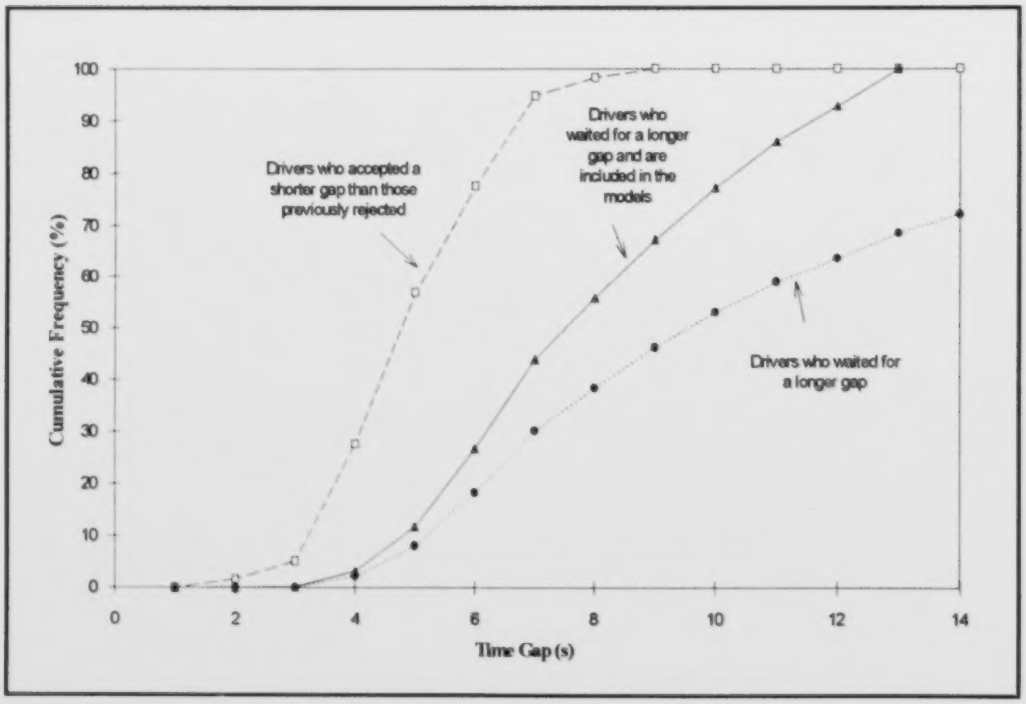
Cumulative Frequency (%)
Time Gap (s)
Drivers who accepted a shorter gap than those previously rejected
Drivers who waited for a longer gap and are included in the models
Drivers who waited for a longer gap

Figure 5.18 Cumulative Distributions of Gaps Accepted by Drivers Who Accepted a Shorter Gap than Previously Rejected and Drivers Who Waited for a Longer Gap

5.2.10 Gap Situations

8652 gap situations were obtained from observing 3434 left turning drivers for the total observation period.

There are 2 possible paradigms for looking at the gap acceptance problem as indicated in Chapter 1. The first paradigm which was chosen in this research focuses on each gap, while the second, focuses on each driver. The underlying statistical principles of the two paradigms are different. The following example explains these differences:

Numbers of drivers accepting first gap (lag) = 1976
Numbers of drivers rejecting first gap (lag) = 1458
Drivers who rejected first gap faced on average number of gaps equal to:
= (8652-1976) / 1458 = 4.58 gaps

For the second paradigm, out of these 4.58 gaps, only one should be selected for each driver. If this gap was picked up randomly, the probability of choosing the accepted gap would be 1 to 4.58.

Number of selected drivers who accepted a gap =
1976 + (1458 * 1/4.58) = 1976 + 318 = 2294 drivers
Number of selected drivers who rejected a gap =
1458 - (1458 * 1/4.58) = 1458 - 318 = 1140 drivers

	Gaps (first paradigm)	Drivers (second paradigm)
Total numbers	8652	3434
Gap accepted included	3434	2294
Gap rejected included	5218	1140
% Accepted included	39.69	66.8

From the previous example, the percentage of accepted gaps is approximately 40%, while it is approximately 67% in the second paradigm. Therefore, the accepted gaps are over-represented in the second paradigm than in the chosen paradigm.

Choice Situations

Some of these 8652 gap situations are not really choice situations. These include the very long gaps that no one rejected and the very short gaps that no one could accept. It was decided to exclude these situations from the data files used for model estimation.

The minimum accepted and the maximum rejected gaps at each location were identified. These values are listed in Table 5.11.

Table 5.11 The Maximum Rejected and the Minimum Accepted Gaps at Each Location

Location	Number of lanes to be crossed	Speed limit (km/h)	Mean speed (km/h)	Maximum rejected gap (s)	Minimum accepted gap (s)
23 Avenue	2	60	54	12.7	1.64
99 Street	2	50	59	11.23	1.38
Keillor Road	3	70	70	8.55	2.33
West Edmonton Mall	2	50	57	11.15	1.04
Stony Plain	5	80	90	11.66	3.8

From Table 5.11, it was noticed that the higher the mean speed, the higher the minimum accepted time gap. Also the wider the road, the higher the minimum accepted gap. This indicated that speed and the width appear to influence a driver's decision.

It is also noted from Table 5.11, that no drivers rejected a gap greater than 13 seconds or accepted a gap less than 1 second. It was therefore decided to delete all situations that include gaps greater than 13 seconds or less than 1 second. These exclusions represent the non-choice situations i.e. very short gaps or very long ones. It is tested later in Chapter 6 whether the results would change if all situations were included, instead of just the reduced data set.

The total number of observed gap situations is 8,652. Excluding the non choice situations (Exclude all records with Time gap > 13 s and Time gap < 1 s) reduced the data to 6,384 choice situations.

It is expected, the distribution of the variables that represent the choice situations which were included in the model estimation, to follow the distribution of variables describing all gap situations, as described in Sections 5.2.1 to 5.2.9.

5.2.11 Correlation Coefficients Among Study Variables

Using a statistical package (SPSS for Windows), the correlation coefficient matrix was obtained for all data sets as shown in Table 5.12. From this matrix the following relations can be detected:

The following variables are highly correlated ($r \geq \pm 0.7$):
Fdelay - Total delay,
Fdelay - Number of Rejected gaps,
Tgap - Space gap,
# of lanes - Speed,
# of lanes - Approach width,

The following variables are moderately correlated ($\pm 0.4 \leq r < \pm 0.7$)
Total delay - Queue delay,
Total delay - Number of rejected gaps,
Total delay - Vehicle Behind,
Flow - Front delay,
Flow - Tgap,
Flow - Space gap,
Flow - Number of rejected gaps.

Table 5.12 **Correlation Coefficients Between Study Variables**

Variable	M/F	Age-Y	Age-M	Pass	Acc-L	Acc-A	Qdelay	Fdelay	Tdelay	Tgap	Speed	Sgap	TypeP	TypeT/B	TypeM	#Rej	Flow	VehBeh	#lanes	Width
M/F	1	-0.10	0.03	0.03	0.07	-0.09	-0.03	-0.06	-0.06	0.00	-0.05	0.00	0.01	0.00	-0.01	-0.01	0.02	-0.08	-0.06	-0.06
Age-Y	-0.10	1	-0.86	-0.06	0.06	-0.10	-0.02	-0.05	-0.05	0.01	-0.03	0.01	0.01	0.00	-0.01	-0.04	-0.01	-0.04	-0.04	-0.04
Age-M	0.03	-0.86	1	0.01	-0.02	0.05	0.05	0.04	0.06	0.00	0.04	0.01	0.00	0.00	0.02	0.03	-0.01	0.05	0.05	0.04
Pass	0.03	-0.06	0.01	1	-0.02	0.04	-0.05	0.06	0.02	0.00	-0.06	-0.02	0.00	0.00	0.00	0.03	-0.04	0.02	-0.07	-0.08
Acc-L	0.07	0.06	-0.02	-0.02	1	-0.89	-0.02	-0.07	-0.06	0.03	0.04	0.04	-0.01	0.00	0.02	-0.07	-0.07	0.00	0.04	0.02
Acc-A	-0.09	-0.10	0.05	0.04	-0.89	1	0.02	0.09	0.09	-0.03	-0.03	-0.04	0.01	-0.01	-0.02	0.10	0.08	0.01	-0.03	-0.01
Qdelay	-0.03	-0.02	0.05	-0.05	-0.02	0.02	1	-0.06	0.64	0.07	0.12	0.10	0.00	-0.01	0.01	-0.10	-0.12	0.31	0.15	0.14
Fdelay	-0.06	-0.05	0.04	0.06	-0.07	0.09	-0.06	1	0.73	-0.14	-0.11	-0.15	0.00	-0.01	0.02	0.93	0.42	0.39	-0.12	-0.13
Tdelay	-0.06	-0.05	0.06	0.02	-0.06	0.09	0.64	0.73	1	-0.05	0.00	-0.04	0.01	-0.01	0.02	0.65	0.24	0.51	0.01	0.00
Tgap	0.00	0.01	0.00	0.00	0.03	-0.03	0.07	-0.14	-0.05	1	0.06	0.95	0.00	0.01	-0.02	-0.16	-0.54	-0.03	0.11	0.10
Speed	-0.05	-0.03	0.04	-0.06	0.04	-0.03	0.12	-0.11	0.00	0.06	1	0.26	0.05	-0.03	0.02	-0.14	-0.14	0.11	0.70	0.68
Sgap	0.00	0.01	0.01	-0.02	0.04	-0.04	0.10	-0.15	-0.04	0.95	0.26	1	0.01	-0.01	-0.01	-0.17	-0.53	0.00	0.25	0.24
TypeP	0.01	0.01	0.00	0.00	-0.01	0.01	0.00	0.00	0.01	0.00	0.05	0.01	1	-0.89	-0.36	0.01	0.02	0.00	-0.03	-0.03
TypeT/B	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.01	0.01	-0.03	-0.01	-0.89	1	-0.02	-0.01	-0.03	0.00	0.03	0.03
TypeM	-0.01	-0.01	0.02	0.00	0.02	-0.02	0.01	0.02	0.02	-0.02	0.02	-0.01	-0.36	-0.02	1	0.02	0.01	0.01	0.00	0.00
#Rej	-0.01	-0.04	0.03	0.03	-0.07	0.10	-0.10	0.93	0.65	-0.16	-0.14	-0.17	0.01	-0.01	0.02	1	0.54	0.33	-0.17	-0.17
Flow	0.02	-0.01	-0.01	-0.04	-0.07	0.08	-0.12	0.42	0.24	-0.54	-0.14	-0.53	0.02	-0.03	0.01	0.54	1	0.13	-0.22	-0.21
VehBeh	-0.08	-0.04	0.05	0.02	0.00	0.01	0.31	0.39	0.51	-0.03	0.11	0.00	0.00	0.00	0.01	0.33	0.13	1	0.17	0.16
#lanes	-0.06	-0.04	0.05	-0.07	0.04	-0.03	0.15	-0.12	0.01	0.11	0.70	0.25	-0.03	0.03	0.00	-0.17	-0.22	0.17	1	0.98
Width	-0.06	-0.04	0.04	-0.08	0.02	-0.01	0.14	-0.13	0.00	0.10	0.68	0.24	-0.03	0.03	0.00	-0.17	-0.21	0.16	0.98	1

Higly correlated r>= 0.7

Average correlation .4=<r<.7

Low correlated r< .4

The remaining variables are poorly correlated or independent ($r < \pm 0.4$) such as:
Queue delay - Front delay,
Time gap - Queue delay,
Time gap - Front delay,
Time gap - Number of rejected gaps,
Speed - Number of rejected gaps,
Flow - Queue delay.

Some variables which were coded in binary form (0 or 1) had a high correlation coefficient between their categories. For example, in considering young and middle age variables, 71% of drivers are middle age, meaning that in 71% of the data young age variable is coded as 0 and middle age variable is coded as 1, leading to a high correlation coefficient between these two variables.

5.3 SUMMARY

This chapter dealt with data that describing driver characteristics and gap attributes. The results of the surveyed left-turn behaviour samples were examined and revised, to provide a suitable set of data for further investigation. As documented in this chapter, this research stage identified a rich and reliable data base required for model estimation.

CHAPTER 6

MODEL DEVELOPMENT AND RESULTS

6.0 INTRODUCTION

This chapter describes model development stages. In the first section, the model development process is described. At the initial stage, different model specifications were estimated and are presented in Section 6.2. According to that initial finding, several utility functions were estimated examining the effect of front delay, number of rejected gaps, and time and space gap perception, to be described in Sections 6.3 to 6.6. The best model, evolved from these investigations, was used to compare driver behaviour from peak to off-peak hours, as well as the effect of front delay and queue delay, (Sections 6.6, and 6.7). Section 6.8 examines the effect of the number of lanes, and width to be crossed, on a driver behaviour.

Section 6.9 describes a further detailed study of the effect of front delay on driver behaviour. Section 6.10 describes the impact of individual variables on the probability of accepting a gap, and the relative importance of these variables as factors in the decision-making process.

6.1 MODEL DEVELOPMENT PROCESS

The model development process started with a utility function that contains as many logical combinations of factors as possible from those initially considered in the tree diagram (Figure 3.2). In this step, when selecting variables to be included in the same model, the correlation coefficients between variables were examined in order to avoid strong colinearity between model variables; for example, Fdelay and #Rej, with 0.93 correlation coefficient, have not been included together in any model.

The model coefficients were estimated using NTELOGIT (1992) program. The average value of variables included in model estimations is given in Table 6.1.

Table 6.1 Average Values of Variables used in the Model Estimations

Variable	Average value
Qdelay	3.62 s
Fdelay	5.54 s
Tdelay	9.16 s
Tgap	4.52 s
Speed	66.29 km/h
Sgap	84.47 m
#Rej	2.79 gap
Flow	16.07 veh/min
VehBeh	35.7 % of times

The estimated model was used to examine the effect of each factor on the utility. If the effect of a variable contradicted the findings of other researchers or the logic, it indicated a problem that required further investigation. For example, in Table 6.2, model 1 result, that included time gap and speed, indicated a problem regarding the effect of speed and front delay. Therefore, it was decided to try including space gap and speed instead, in model 2. The result of model 2 indicated a problem regarding the effect of front delay. Therefore, #Rej instead of Fdelay was included to capture the effect of waiting time at the front of the queue. Other models, included in Table 6.2, are described in details in Section 6.2.

It is important to indicate that model development was a sequential process that followed logical steps. In this step, the focus was to develop a model that served as a basis for examining the effect of various variables on drivers' behaviour. Following the previous step, with help from the following statistical tests, the "best" model has evolved. This model was then used for further investigation of special issues and for the examination of the relative importance of the variables.

Table 6.2 Results of Different Model Estimations Considered in the Initial Stage of Model Development

Model #		1	2	3	4	5	6	7	8	9
Parameter										
Constant	X:	-8.799	-.918	-1.23	-.844	-.0108	-.023	-2.332	-2.682	-2.068
	t:	-9.391	-1.35	-1.81	-1.27	-.017	-.036	-3.395	-3.897	-3.10
Gender	X:	+.6970	+.664	+.705	+.675	+.6761	+.669	+.7212	+.7535	+0.761
	t:	+6.658	+6.37	+6.70	+6.67	+6.770	+6.71	+6.820	+7.073	+7.34
Age-Y	X:	+.297	+.328	+.358	+.398	+.3497	+.344	+.3110	+.3494	+0.303
	t:	+1.21	+1.36	+1.47	+1.70	+1.509	+1.49	+1.271	+1.421	+1.26
Age-M	X:	-.156	-.137	-.144	-.068	-.1066	-.114	-.1710	-.1694	-0.201
	t:	-.682	-.612	-.637	-.311	-.493	-.526	-.750	-.740	-.90
Pass	X:	-.371	-.342	-.366	-.459	-.4889	-.484	-.3753	-.3874	-0.461
	t:	-3.41	-3.18	-3.38	-4.40	-4.754	-4.72	-3.443	-3.531	-4.32
Acc-L	X:	-.258	-.261	-.247	-.399	-.4147	-.414	-.1559	-.1485	-0.270
	t:	-1.19	-1.21	-1.14	-1.89	-1.975	-1.97	-.718	-.681	-1.26
Acc-A	X:	-.153	-.164	-.141	-.289	-.2737	-.280	-.1008	-.0819	-0.240
	t:	-.73	-.79	-.68	-1.42	-1.352	-1.38	-.482	-.390	-1.16
Qdelay	X:	+.029	+.030	+.028				+.0313	+.0286	+0.042
	t:	+4.62	+4.72	+4.31				+4.817	+4.394	+6.66
Fdelay	X:	-.098	-.091					-.0855		
	t:	-10.73	-10.42					-9.462		
Tdelay	X:				-.017	-.0097	-.005			
	t:				-3.13	-1.910	-1.16			
TGap	X:	+1.457								
	t:	+35.68								
Speed	X:	+.026	-.076	-.079	-.069	-.0614	-.061	-.0770	-.0797	-0.072
	t:	+5.76	-15.19	-15.52	-14.40	-13.37	-13.36	-14.99	-15.33	-14.41
Sgap	X:		+.080	+.082	+.076	+.0709	+.071	+.0822	+.0838	+0.079
	t:		+35.38	35.19	+36.03	+37.32	+37.33	+35.19	+35.01	+35.57
TypeP	X:	-.489	-1.259	-1.278	-1.142	-1.078	-1.051	-1.187	-1.194	-1.189
	t:	-.59	-2.08	-2.12	-1.94	-1.820	-1.77	-1.950	-1.966	-2.01
TypeT/B	X:	-.672	-1.392	-1.416	-1.252	-1.191	-1.159	-1.277	-1.297	-1.232
	t:	-.78	-2.15	-2.19	-1.99	-1.880	-1.83	-1.963	-1.997	-1.94
TypeM	X:	-1.607	-2.559	-2.615	-2.577	-2.612	-2.538	-2.505	-2.571	-2.509
	t:	-1.44	-2.58	-2.62	-2.73	-2.785	-2.72	-2.443	-2.501	-2.55
#Rej	X:			-.242					-.2271	
	t:			11.73					-10.71	
Flow	X:	+.099	+.088	+.117	+.052			+.0997	+.1241	+0.073
	t:	+12.06	+11.34	+13.45	+7.33			+11.87	+13.50	+9.13
VehBeh	X:	+.205	+.197	+.225	+.156	+.2128		+.1510	+.1790	-0.278
	t:	+1.69	+1.63	+1.86	+1.32	+1.827		+1.228	+1.460	-2.45
#lanes	X:	-.440	-.562	-.582	-.464	-.5291	-.511			
	t:	-5.95	-7.12	-7.29	-6.13	-7.160	-7.00			
Width	X:									
	t:									
99St	X:							-.9418	-.7570	-1.171
	t:							-4.624	-3.681	-5.86
KE	X:							-.3599	-.3186	-0.335
	t:							-1.970	-1.738	-1.86
WE	X:							-.0397	-.0079	-0.085
	t:							-.233	-.046	-0.51
SP	X:							-2.280	-2.257	-2.169
	t:							-7.875	-7.744	-7.64

Table 6.2 (Cont.....)

Models Statistics:

Model #	1	2	3	4	5	6	7	8	9
LL(0)	-4425.05	-4425.05	-4425.05	-4425.05	-4425.05	-4425.05	-4425.05	-4425.05	-4425.05
LL(β)	-1402.92	-1423.12	-1396.34	-1504.50	-1531.17	-1532.84	-1391.65	-1371.57	-1442.74
ρ2(0)	0.6830	0.6784	0.6845	0.6600	0.6540	0.6536	0.6855	0.6900	0.6740
ρ2(0)(Aic)	0.6791	0.6746	0.6806	0.6564	0.6506	0.6504	0.6810	0.6855	0.6697
%correct	86.85	86.65	86.90	85.86	85.58	85.56	86.97	87.15	86.45

The statistical procedures used in the model development process are described as follows:

1- Examine the sign of the coefficient estimates. If the coefficient estimate for a variable has a sign that is not in agreement with prior expectations, or is not logical, then the variable may be dropped or different forms of the variables may be included, keeping the rest of the utility function fixed.

2- Examine the magnitude of t-value for the estimated coefficients. The higher the t-value, the lower the standard error for the estimated parameter. The following are the limits of the t-value used in this research.

- If the absolute magnitude of the t-value is greater than 1.65, the coefficient estimate for the variables is considered to be statistically different from zero at a 90% level of confidence, and the corresponding variable is considered to influence a driver's choice

- If the absolute magnitude of the t-value is between 1.28 (80% level of confidence) and 1.65, the coefficient estimate for the variables is considered to be acceptable (Ortuzar and Willumsen, 1990).

- If the absolute magnitude of the t-value is less than 1.28, the coefficient estimate for the variables is considered to be statistically not different than zero.

3- Examine the relative values of the coefficients, e.g., the relative values of the coefficient estimates for acceleration capability groups, which should be logical or as expected.

4- Compare the overall model fit, use the modified likelihood ratio index to compare more than one model as follows:

$\rho^2(0)$(Aic) is used when comparing two models estimated using the same set of observations

$\rho^2(c)$(Aic) is used when comparing two models estimated using different sets of observations (with different proportions of sampled individuals selecting the various alternatives).

When comparing two models (if the index of the two models differs by 0.01 or more), the model with the higher modified likelihood ratio index is considered to be superior to the other model (Horowitz, 1982)

5- Use the likelihood ratio test to test the hypothesis that all coefficient estimates are equal to zero, and all coefficient estimates except for alternative specific constants, are zero

6- If one model is a restriction of another model, likelihood ratio test is also used to test whether or not to accept the null hypothesis regarding the restrictions, as follows:

$$X^2_{calculated} = -2 [L(\beta_R) - L(\beta_U)]$$

where $L(\beta_R)$ = log likelihood for the restricted model,
$L(\beta_U)$ = log likelihood for the unrestricted model

If the calculated value is less than the X^2 value at a 95% level of confidence, with the degree of freedom equal to the difference in the degree of freedom between the unrestricted model and the restricted model, the null hypothesis would be accepted.

6.2 INITIAL MODEL FORMULATIONS

A variety of utility function specifications using different combinations of the variables were considered in the initial stages of model development. Models were estimated first using data from each location individually. The resulting models were greatly different, probably because of the relatively small sample size and the narrow range of variables at each location. It was therefore decided to use the whole data set for model estimations. The number of lanes, width, or location specific constants were included to capture the effect of the differences among the locations. The major model structures from this preliminary stage are presented in Table 6.2. The Table lists all variables included in model estimations, the estimated coefficients "X" and the t-values "t" for the different models considered. Table 6.2 also lists the parameters used to test the statistical validity of the models. The following is a discussion of model estimation results.

Model 1: The results of model estimation are shown as Model 1 in Table 6.2 and can be presented as follows:

Signs of all coefficients, except speed and front delay, were consistent with what was expected for all variables. The negative sign for front delay variable and the positive sign for speed variable indicated that as front delay increases, the probability of accepting a gap decreases and as speed of opposing vehicles increases, the probability of accepting a gap increases. Both speed and front delay coefficients were different from zero at 90% level of confidence. Possible explanation regarding the speed is that its effect is already included in the time gap. For front delay, the reason may be the correlation between flow and front delay (0.42) or it may be the number of rejected gaps, not the front delay, that affects a driver's decision.

The coefficients of other variables such as gender, presence of passengers, queue delay, front delay, time gap, flow, vehicle behind, and number of lanes were different from zero at 90% level of confidence. The coefficients of the variables: age, acceleration capability, and type of opposing vehicles were not different from zero at 90% level of confidence. The t-statistic for the estimated coefficients for Age-Y and TypeM were considered acceptable.

Following these results, other utility functions were estimated using space gap instead of time gap (Model 2 in Table 6.2), and including the number of rejected gap variable in the utility function instead of front delay variable (Model 3 in Table 6.2). The results of model estimation for these utility functions are discussed below.

Model 2: Using space gap and speed instead of time gap and speed is shown as Model 2 in Table 6.2. The results of the model estimation are as follows:

The sign of the speed coefficient became consistent with what was expected. As speed increases, the probability of accepting a gap decreases. The type of opposing vehicle coefficient became different from zero at 90% level of confidence. Still the sign of the coefficient of front delay was not logical. The likelihood ratio index for model 1 was slightly better than that for model 2.

Model 3: This model used the number of rejected gaps instead of front delay. The results are shown as Model 3 in Table 6.2 and can be summarized as follows:

The goodness-of-fit measure was slightly better than Models 1 and 2, but the sign of the coefficient for the number of rejected gaps was not logical. The negative sign suggested that as the number of rejected gaps increases, the probability of accepting a gap decreases. The coefficients and t-statistics values for all other variables were almost the same as in model 2.

Model 4 : In this model total delay (instead of queue delay and front delay) was used in the utility function. The results of the model estimation (which are shown as Model 4 in Table 1) are as follows:

The sign of the total delay coefficient was not reasonable, indicating that as total delay increases, the probability of accepting a gap decreases. This may be due to its correlation with flow. The goodness-of-fit measure (ρ^2) was lower than those for models 1, 2, and 3. Some coefficients became different from zero at 90% level of confidence, such as Age-Y and Acc-L, while Veh.Beh. coefficient was considered acceptable.

Model 5: The flow variable was excluded from Model 4. The results of the model estimation are shown as Model 5 in Table 6.2.

Using the likelihood ratio statistics to test the null hypothesis that the coefficient for the flow is equal to zero:

X^2 = -2 [-1531.17+1504.50] = 53.34

X^2 value for one degree of freedom and 95% confidence level = 3.8

Therefore, the null hypothesis can be rejected. Excluding the flow variable from the model also did not improve the sign of total delay coefficient. Thus, it was decided not to exclude the flow variable from the model.

Model 6: Since there is a 0.51 correlation coefficient between the total delay and the vehicle behind variable, it was decided to delete the vehicle behind variable from the model. The results are shown as Model 6 in Table 6.2.

Using the likelihood ratio statistics to test the null hypothesis that the coefficients for the flow and vehicle behind are equal to zero:

$X^2 = -2 [L(\beta_R) - L(\beta_U)]$

$= -2 [-1532.84+1504.50] = 55.68$

X^2 value for two degree of freedoms and 95% confidence level = 6

Therefore, the null hypothesis can be rejected. Excluding the flow and vehicle behind variables from the model specification also did not improve the sign of total delay coefficient. The sign of the total delay was not as expected, but its coefficient estimate was not different from zero at 90% level of confidence.

All previous model estimations so far, had the problem that the sign of the following variables, if included in model specifications, were not logical: front delay, number of rejected gaps, or total delay. Combining data from all intersections with different ranges of delay may have led to that problem. It was therefore decided to include Location Specific constant variables to account for the dissimilarity between intersections.

Model 7 and 8 : Model 7 and 8 had the same specifications as Model 2 and 3 except including location specific constants, instead of the number of lanes variable. Coefficient values and t-statistics for all variables were almost the same as for Model 2 and 3. Coefficients of all location specific constants, except for WE, were different from zero at 90% level of confidence. The utility function number 7 is the same as number 8 except that front delay is included in Number 7 while number of rejected gaps is included in Number 8.

The goodness-of-fit measure (ρ^2) was higher for the models that included location specific constants, than the models that included the number of lanes. The goodness of fit measure for Model 8 in Table 6.2 (0.686) that contains the number of rejected gaps was slightly higher than Model 7 (0.681) that contains front delay. In both models all the estimated coefficients, except for Fdelay in model 7 and #Rej in model 8, have signs which are consistent with what was expected. The models show that the probability of accepting a gap decreases as the front delay or the number of rejected gaps increases which was not expected. All the estimated coefficients, except those for age and acceleration capabilities, are statistically different from zero.

Model 9 : Same as model number 8 except excludes number of rejected gaps from the model. The results are shown as Model 9 in Table 6.2.

Using the likelihood ratio statistics to test the null hypothesis that the coefficients for the #Rej is equal to zero:

$$X^2 = -2 [L(\beta_R) - L(\beta_U)]$$
$$= -2 [-1442.74+1371.57] = 142.34$$

X^2 value for two degree of freedoms and 95% confidence level = 3.84

Therefore, the null hypothesis can be rejected. The sign of the vehicle behind coefficient became inconsistent with what was expected. Therefore, excluding front delay (or number of rejected gaps) from the model was not acceptable.

Summary of the initial models estimations:

A variety of utility function specifications including various combinations of the variables were considered in the initial stage of model development. Figure 6.1 presents a comparison between the different models considered. The figure shows the variables included in each model, goodness-of-fit measure (ρ^2) and coefficients evaluation.

The results of these preliminary model estimations can be summarized as follows:

1- Including the time gap and the speed in one model was judged as inappropriate. Detailed study for the time gap, the space gap and speed is required.

2- Some coefficients of variables always had the expected signs and these signs were different from zero at 90% level of confidence. These variables included: gender, presence of passengers in the turning vehicle, queue delay, space gap size, speed, type of opposing vehicle, opposing flow, number of lanes, and location specific constants for 99St, Keillor road, and Stony Plain. Regarding the type of opposing vehicle, the probability of rejecting a gap increases in the following order: Bicycle, Passenger car, Truck or Bus, and Motorcycle. Regarding location specific constants, the probability of rejecting a certain gap increases in the following order: 23 Avenue, WEM, Keillor Road, 99 Street, and Stony Plain location.

3- Some variables always had the expected sign but were not different from zero at 90% level of confidence. These were: age of the driver, acceleration capability (Average), and Location specific constant (WEM), if they were included in the model.

4- Some coefficients had signs that were consistent with what was expected and were different from zero in some models and not different in others such as those for Age-Y, Acc-L, Veh.Beh..

5- The signs of some variables, if included in the models, were never logical. These variables were; front delay, total delay, and number of rejected gaps. This may be explained by the low value of front delay and number of rejected gaps experienced by drivers. As described in Chapter 5, front delay ranged from 0 to 69 seconds with an average value of 5.5 seconds in all locations and the number of rejected gaps ranged between 0 and 34 gaps with an average of 2.79. There is a need for further analysis of the effect of the number of rejected gaps and the front delay.

6- As queue delay increases, the probability of accepting a gap increases. An opposite relation was obtained for front delay, which was not expected.

7- Using location specific constants instead of number of lanes gave a better model fit.

Model#	M/	Age		Pass	Acc.		Delay			Gap		Speed	Type			#Rej	Flow	Veh.	#lane	Width	L. S.C.				ρ2
	F	Y	M		L	A	Qdelay	Fdelay	Tdelay	Tgap	Sgap		P	T/B	M			Beh.			99St	KE	WE	SP	
Model 1									X		X					X				X	X	X	X	X	0.679
Model 2									X	X						X				X	X	X	X	X	0.675
Model 3								X	X	X										X	X	X	X	X	0.681
Model 4							X	X		X						X				X	X	X	X	X	0.656
Model 5							X	X		X						X	X			X	X	X	X	X	0.651
Model 6							X	X		X						X	X	X		X	X	X	X	X	0.650
Model 7									X	X						X			X	X					0.681
Model 8								X	X	X									X	X					0.686
Model 9								X	X	X						X			X	X					0.670

Expected sign & Highly significant

Unexpected sign & Highly significant

Expected sign & Not significant

Unexpected sign & Not significant

X Not included in the model

Figure 6.1 Summary Results of Initial Model Estimations

6.3 EXAMINING THE NON-LINEARITY OF THE EFFECT OF FRONT DELAY

- Including the front delay variable in any utility function so far, produced an unexpected result (probability of accepting a gap decreases as front delay increases). This result contradicted the findings of other researchers (for instance, Mahmassani and Sheffi 1981, Kittelson and Vandehey 1991, and Kyte et al. 1991). Those researchers indicated that the size of the accepted gap decreases with increasing the delay. Therefore, effect of front delay required further investigation.

Since the underlying function of the effect of front delay is not known, it was logical to start with the linear, in parameter function. In this function, the front delay variable (Fdelay) was split into three variables of arbitrary ranges as follows:

Fdelay1 = 0 - 15 s
Fdelay2 = 15 - 30 s
Fdelay3 = > 30 s

If the coefficient estimates for these variables were different, that would imply non linearity in the effect of front delay.

Numbers of choice situations involving these ranges of front delay are given in Table 6.3.

Table 6.3 Numbers of Choice Situations Involving Each Front Delay Range

Front delay variable	Number of choice situations involved
Fdelay1 (0 - 15 s)	5718
Fdelay2 (15.01 - 30 s)	509
Fdelay 3 (> 30 s)	157
Total numbers of choice situations	6384

6.3.1 Data Coding

In case of gap acceptance, drivers while waiting at the intersection do not know how long they are going to be delayed. Therefore, the following method of coding was used:

Fdelay1 = Fdelay	if Fdelay ≤15 s
= 15	otherwise
Fdelay2 = 0	if Fdelay ≤ 15 s
= (Fdelay -15)	if 15 < Fdelay ≤ 30 s
= 15	otherwise
Fdelay3 = 0	if Fdelay ≤ 30 s
= (Fdelay - 30)	otherwise

6.3.2 Model Estimations

Table 6.4 shows the results of different model formulations regarding the effect of front delay on gap acceptance decision. These models are based on Model 7 in Table 6.2. Model 1 represents a function that used front delay as one variable. Model 2 is the same utility function as number 1 except it includes front delay as three variables implying the non linearity of behaviour. Results of estimating the two models indicated that:

- The single front delay variable in Model 1 had a coefficient estimate of -.0855 that indicated that the probability of accepting a gap decreases with increasing front delay which was not logical.

- The results of estimating the utility function that used front delay as three variables, showed that for front delay less than or equal to 30 seconds, the probability of accepting a gap decreases with increasing front delay. For front delay greater than 30 seconds, the results showed that as front delay increases, the probability of accepting a gap increases. This change in behaviour may be due to either the learning process, or to frustration, or a combination of both.

Table 6.4 Examining the Non Linearity of Front Delay Effect

Model #		1	2	3
Parameters				
Constant	X: t:	-2.3317 -3.395	-2.3454 -3.364	-2.3883 -3.813
Gender	X: t:	+.7212 +6.820	+.7101 +6.668	+.6686 +6.405
Age-Y	X: t:	+.3110 1.271	+.3024 +1.229	
Age-M	X: t:	-.1710 -.750	-.1615 -.705	
Pass	X: t:	-.3753 -3.443	-.3886 -3.533	-.4126 -3.772
Acc-L	X: t:	-.1559 -.718	-.1246 -.570	
Acc-A	X: t:	-.1008 -.482	-.0881 -.419	
Qdelay	X: t:	+.0313 +4.817	+.0298 +4.525	+.0286 +4.405
Fdelay	X: t:	-.0855 -9.462		
Fdelay1	X: t:		-.1352 -9.278	-.1387 -9.527
Fdelay2	X: t:		-.0710 -2.163	-.0674 -2.061
Fdelay3	X: t:		+.0865 +2.483	+.0876 +2.485
Speed	X: t:	-.0770 -14.988	-.0777 -14.987	-.0776 -14.993
SGap	X: t:	+.0822 +35.185	+.0832 +35.004	+.0828 +35.101
TypeP	X: t:	-1.1870 -1.950	-1.2255 -1.978	-1.2387 -2.028
TypeT/B	X: t:	-1.2769 -1.963	-1.3095 -1.982	-1.3168 -2.018
TypeM	X: t:	-2.5049 -2.443	-2.5094 -2.409	-2.6006 -2.518
Flow	X: t:	+.0997 +11.871	+.1908 +12.619	+.1098 +12.721
VehBeh	X: t:	+.1510 +1.228	+.2333 +1.861	+.2521 +2.016
99St	X: t:	-.9418 -4.624	-.9854 -4.805	-1.0190 -4.996
KE	X: t:	-.3599 -1.970	-.4109 -2.237	-.4461 -2.446
WE	X: t:	-.0398 -.233	-.0610 -.355	-.0698 -.411
SP	X: t:	-2.2801 -7.875	-2.3772 -8.119	-2.3889 -8.211

Table 6.4 (cont...)

Models Statistics:

Model #	1	2	3
LL(0)	-4425.05	-4425.05	-4425.05
LL(β)	-1391.65	-1372.25	-1380.36
$\rho^2(0)$	0.686	0.690	0.688
$\rho^2(0)$(Aic)	0.681	0.685	0.684
%correct	86.97	87.12	87.03

Model 1: includes front delay as one variable,
Model 2: includes front delay as 3 variables,
Model 3: includes front delay as 3 variables and excluding age and acceleration capability.

- In the utility function number 2, all the coefficients had signs which were consistent with what was expected. All coefficients except the ones for age, acceleration capability and location Specific constants for the West Edmonton Mall entrance location were statistically different from zero at 90% level of confidence.

- The value of goodness of fit measure (ρ^2) for the model that included front delay as three variables (0.690), was higher than that for the model that used Fdelay as one variable (0.686), indicating that model 2 is a better model.

- Using the likelihood ratio statistics to test the following null hypothesis.

-Null hypothesis: $\beta_{Fdelay1} = \beta_{Fdelay2} = \beta_{Fdelay3}$

$$X^2_{calculated} = -2 [LL(\beta_R) - LL(\beta_U)]$$
$$= -2 [- 1391.649 + 1372.255]$$
$$= 38.78$$

X^2 value for 2 degree of freedom and 95% significance level = 6

Therefore, the null hypothesis of linear front delay variables could be rejected. This result indicated that the two models are different.

- Model 3 in Table 6.4, is the same as model 2 except in excluding the variables that are not different from zero at 90% level of confidence. The results showed that the

changes in the estimated coefficients for the other parameters were very small. The changes in the goodness of fit measure and the percentage correct were relatively small.

Using the likelihood ratio statistics to test the null hypothesis that the coefficient estimates for age and acceleration capability are equal to zero:

X^2 = -2 [-1380.3584+1372.2546] = 16.21

X^2 value for four degree of freedom and 95% confidence level = 9.45

Therefore, the null hypothesis can be rejected. Thus, it was decided not to exclude these variables from the model.

Covariance matrix information (output from NTELOGIT program) was used to test the following null hypothesis:

Null hypothesis: $\beta_{(Fdelay1)} = \beta_{(Fdelay2)}$

$$t = \frac{\beta_1 - \beta_2}{\sqrt{\text{var}(\beta_1) + \text{var}(\beta_2) - 2\,\text{cov}(\beta_1, \beta_2)}}$$

$$t = \frac{-.135156 + .070988}{\sqrt{.000212 + .001077 - 2(-.000184)}} = 1.58$$

t-statistics value at 90% level of confidence = 1.65

The null hypothesis could not rejected. Therefore, $\beta_{(Fdelay1)} = \beta_{(Fdelay2)}$

Similar calculation for the null hypothesis: $\beta_{(Fdelay2)} = \beta_{(Fdelay3)}$

$$t = \frac{\beta_2 - \beta_3}{\sqrt{\text{var}(\beta_2) + \text{var}(\beta_3) - 2\,\text{cov}(\beta_2, \beta_3)}}$$

$$t = \frac{-.070988 - .086461}{\sqrt{.001077 + .001213 - 2(-.000726)}} = -2.57$$

The null hypothesis could be rejected. Therefore, $\beta_{(Fdelay2)} \neq \beta_{(Fdelay3)}$

6.4 EXAMINING THE NON-LINEARITY OF THE EFFECT OF NUMBER OF REJECTED GAPS

Results of Model 3 in Table 6.2 indicated that, using the number of rejected gaps (#Rej) produced unexpected results (as number of rejected gaps increases, the probability of accepting a gap decreases). This result is similar to the result obtained when including the front delay, as described in Section 6.3. It was therefore decided to split #Rej variable into three variables similar to the front delay variables.

To compare the effect of Fdelay and #Rej on a driver's decision, three ranges of #Rej corresponding to Fdelay ranges were estimated. Distributions of the number of rejected gaps for each group of Fdelay were used as shown in Figures 6.2, 6.3, and 6.4.

The following ranges of #Rej were found to represent at least 80% of the total number of rejected gaps in each group of Fdelay.

#Rej1 = 0 - 3 gaps
#Rej2 = 4 - 14 gaps
#Rej3 = >14 gaps

6.4.1 Coding Number of Rejected Gap Variables

Similar to the coding front delay variables that was described in section 6.2.1, #Rej was coded as follows. Number of choice situations that involved each range of #Rej is given in Table 6.5.

#Rej1 = #Rej	if #Rej ≤ 3
= 3	otherwise
#Rej2 = 0	if #Rej ≤ 3
= (#Rej - 3)	if 3 < #Rej ≤ 14
= 11	otherwise
#Rej3 = 0	if #Rej ≤ 14
= (#Rej - 14)	otherwise

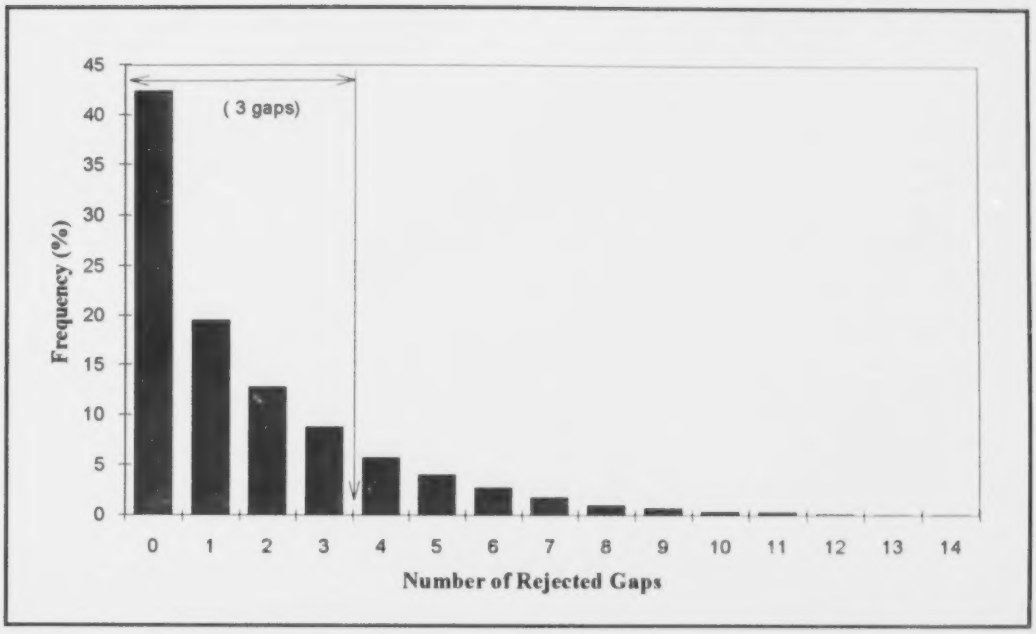

Figure 6.2 Distribution of Number of Rejected Gaps for Front Delay Range between 0 - 15 s

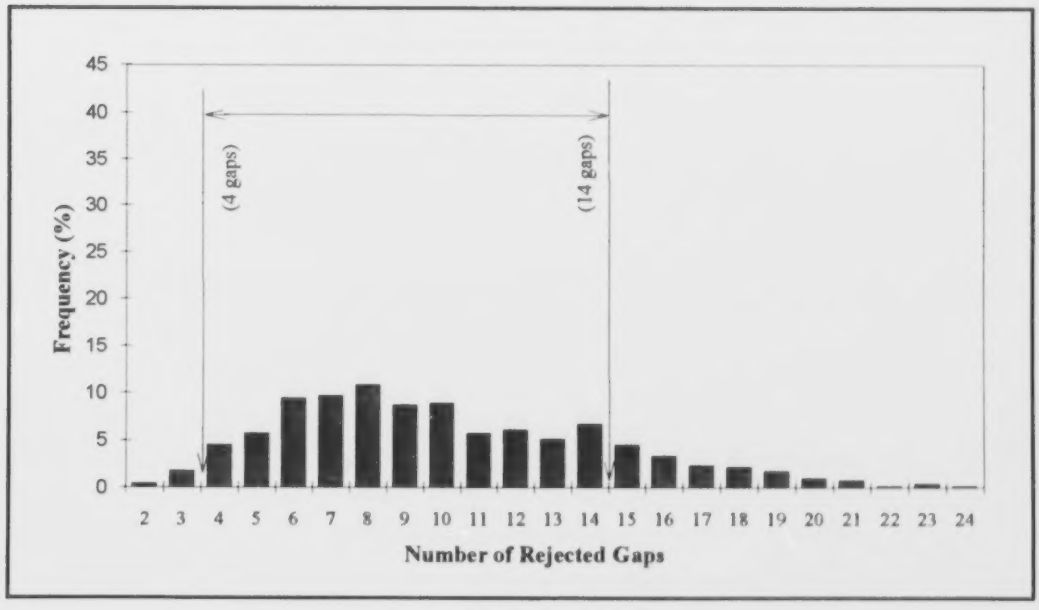

Figure 6.3 Distribution of Number of Rejected Gaps for Front Delay Range between 15 - 30 s

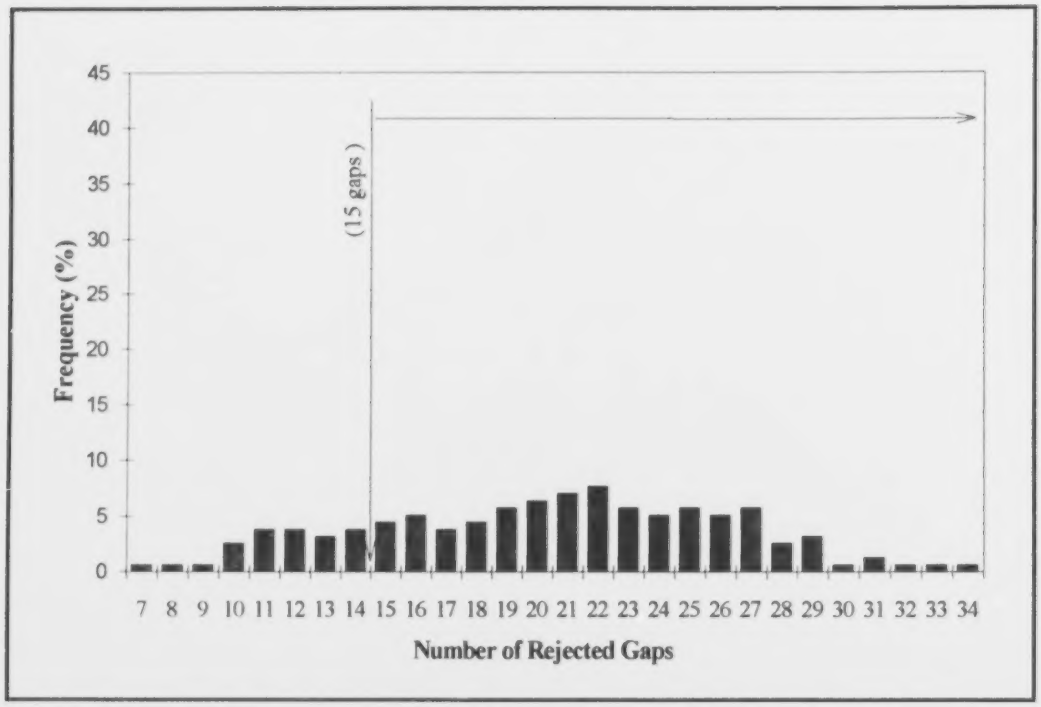

Figure 6.4 Distribution of Number of Rejected Gaps for Front Delay > 30 s

Table 6.5 Number of choice Situations Involving Each Range of Number of Rejected Gaps

Number of Rej. Gaps variable	Number of choice situations involved
#Rej1 (0 -3)	4775
#Rej2 (4-14)	1397
#Rej 3(>14)	212
Total choice situations	6384

6.4.2 Model Estimations

Two model specifications were estimated based on Model 8 in Table 6.2. One model included the number of rejected gaps as one variable (implying the linearity of behaviour), the other model included the number of rejected gaps as three variables. The results of model estimations are presented in Table 6.6. The following is a discussion of the results.

Model 1 in Table 6.6 includes the number of rejected gaps as one variable. The result showed that as the number of rejected gaps increases, the probability of accepting a gap decreases. This result was not reasonable and also contradicts the findings of other researchers. Model number 2 is the same utility function as number 1 except it included the number of rejected gaps as three parameters implying the non linearity in behaviour. The result was consistent with the result of the effect of the front delay. The results showed that for number of rejected gaps less than or equal to 14, as the number of rejected gaps increases, the probability of accepting a gap decreases. For number of rejected gaps greater than 14, the results showed that as the number of rejected gaps increases, the probability of accepting a gap increases but the coefficient estimate for #Rej3 was not statistically different from zero (t-value = .009).

In the utility function number 2, signs of all the coefficients were consistent with what was expected. All coefficients except the ones for age, acceleration capability, a location specific constant for the WEM location, and number of rejected gaps (#Rej3), were statistically different from zero.

Table 6.6 Examining the Non-linearity of the Effect of Number of Rejected Gaps

Model #		1	2
Parameters			
Constant	X: t:	-2.68191 -3.897	-2.63873 -3.803
Gender	X: t:	+.75346 +7.073	+.70843 +6.560
Age-Y	X: t:	+.34944 +1.421	+.25432 +1.011
Age-M	X: t:	-.16935 -.740	-.22241 -.949
Pass	X: t:	-.38739 -3.531	-.39428 -3.517
Acc-L	X: t:	-.14849 -.681	-.10822 -.486
Acc-A	X: t:	-.08185 -.390	-.07065 -.330
Qdelay	X: t:	+.02863 +4.394	+.02427 +3.592
Speed	X: t:	-.07967 -15.333	-.08366 -15.680
SGap	X: t	+.08384 +35.009	+.08671 +34.413
TypeP	X: t:	-1.19439 -1.966	-1.15632 -1.895
TypeT/B	X: t:	-1.29663 -1.997	-1.26827 -1.943
TypeM	X: t:	-2.57137 -2.501	-2.41701 -2.309
#Rej	X: t:	-.22711 -10.705	
#Rej1	X: t:		-.69530 -12.117
#Rej2	X: t:		-.13166 -3.831
#Rej3	X: t:		+.00565 +.099
Flow	X: t:	+.12412 +13.504	+.15336 +15.308
VehBeh	X: t:	+.17901 +1.460	+.35406 +2.785
99St	X: t:	-.75695 -3.681	-.91748 -4.379
KE	X: t:	-.31857 -1.738	-.41838 -2.256
WE	X: t:	-.00794 -.046	-.02414 -.139
SP	X: t:	-2.25657 -7.744	-2.44484 -8.224

Table 6.6 (cont...)

Models Statistics:

Model #	1	2
LL(0)	-4425.05	-4425.05
LL(β)	-1371.57	-1320.30
$\rho^2(0)$	.690	.702
$\rho^2(0)$(Aic)	.686	.697
%correct	87.15	87.64

Model 1: Includes number of rejected gaps as one variable

Model 2: Include number of rejected gaps as three variables

The likelihood ratio test was used to test the following null hypothesis:

Null hypothesis: $\beta_{(\#Rej1)} = \beta_{(\#Rej2)} = \beta_{(\#Rej3)}$

$$X^2_{calculated} = -2\,[\,LL(\beta_R) - LL(\beta_U)]$$
$$= -2\,[\,-1371.573 + 1320.299\,]$$
$$= 102.548$$

$LL(\beta_R) = -1371.573$ for model using #Rej variable as one variable

$LL(\beta_U) = -1320.299$ for model using #Rej1, #Rej2, and #Rej3

X^2 value for 2 degree of freedom and 95% significance level = 6

Therefore, the null hypothesis of linearity of number of rejected gaps could be rejected. This indicates that the two models are different.

Covariance matrix information, that was obtained as an output from NTELOGIT program, was used to test the following null hypothesis:

Null hypothesis: $\beta_{(\#Rej1)} = \beta_{(\#Rej2)}$

$$t = \frac{\beta_1 - \beta_2}{\sqrt{\text{var}(\beta_1) + \text{var}(\beta_2) - 2\,\text{cov}(\beta_1, \beta_2)}}$$

$$t = \frac{-.695304 + .131661}{\sqrt{.003293 + .001181 - 2(-.000596)}} = -7.49$$

t-statistics value at 90% level of confidence = 1.65

The null hypothesis could be rejected. Therefore, $\beta_{(\#Rej1)} \neq \beta_{(\#Rej2)}$

Similar calculation for the null hypothesis: $\beta_{(\#Rej2)} = \beta_{(\#Rej3)}$

$$t = \frac{\beta_2 - \beta_3}{\sqrt{\text{var}(\beta_2) + \text{var}(\beta_3) - 2\,\text{cov}(\beta_2, \beta_3)}}$$

$$t = \frac{-.131661 - .005646}{\sqrt{.001181 + .003222 - 2(-.000946)}} = -2.57$$

The null hypothesis could be reject. Therefore, $\beta_{(\#Rej2)} \neq \beta_{(\#Rej3)}$

6.4.3 Comparison Between the Effect of Front Delay and Number of Rejected Gaps

Comparing utility function number 2 in Table 6.4 (that included front delay as three variables) with the utility function number 2 in Table 6.6 (that included number of rejected gaps as three variables), the following results can be inferred:

Although the sign of the coefficient estimate for #Rej3 was positive, it was statistically not different from zero (t- ratio = +.099). The coefficient estimate for #Rej1 and #Rej2 were statistically different from zero. The coefficient estimates, for all Fdelay variables, were statistically different from zero. The modified likelihood ratio index $\rho^2(0)$(Aic) for the model that includes the number of rejected gaps is slightly higher than that for the model that includes front delay but the difference between the two indices is only 0.01.

From the previous review of the two models, since both models fit the data equally, and because of the problem of the insignificance of #Rej3, it was decided to use front delay instead of the number of rejected gaps for any further investigation.

6.5 EXAMINING THE EFFECT OF TIME GAP AND SPACE GAP

The following section describes different utility functions that were estimated to examine the effect of time gap versus space gap on driver decisions to accept or reject a gap. Results of different model estimations are shown in Table 6.7.

Model 1 in Table 6.7, that includes space gap and speed, was discussed before, as Model 2 in Table 6.4 in section 6.2.2

Model 2 includes time gap and speed. The results of this model estimation showed that the coefficient estimate for the speed had a positive sign which was not expected (as speed increases, the probability of accepting a gap increases). This result contradicts findings from previous researchers.

This result supports the finding from a previous research by Ashworth and Bottom (1977) and contradicts the findings of others (for instance, Cooper et al., 1976 and Uber and Hoffmann, 1988).

Ashworth and Bottom found that for the same measured gap size (in time), the mean speed of the approaching vehicles that led to accepted gaps is significantly higher than the mean speed of vehicles associated with rejected gaps. They explained this finding as: for the same gap size in time, the higher the speed the higher the distance gap that makes it acceptable by drivers. However in this study, it was found that the correlation coefficient between speed and space gap, (as shown in Table 5.12) to be 0.26 which suggests that the two variables are poorly correlated or independent.

Table 6.7 Examining the Effect of Space Gap and Time Gap

Model #		1	2	3	4
Parameters					
Constant	X:	-2.34542	-10.0969	-9.2121	-9.1158
	t:	-3.364	-10.378	-9.585	-27.158
Gender	X:	+.71005	+.72111	+.69507	+.6634
	t:	+6.668	+6.776	+6.584	+6.414
Age-Y	X:	+.30243	+.25728	+.28513	
	t:	+1.229	+1.028	+1.146	
Age-M	X:	-.16151	-.18186	-.14067	
	t:	-.705	-.782	-.608	
Pass	X:	-.38855	-.41001	-.40922	-.4404
	t:	-3.533	-3.699	-3.717	-4.027
Acc-L	X:	-.12458	-.15097	-.14268	
	t:	-.570	-.685	-.650	
Acc-A	X:	-.08806	-.09398	-.08326	
	t:	-.419	-.443	-.394	
Qdelay	X:	+.02980	+.02892	+.02884	+.02812
	t:	+4.525	+4.450	+4.461	+4.419
Fdelay1	X:	-.13516	-.14030	-.14222	-.14620
	t:	-9.278	-9.500	-9.713	-9.995
Fdelay2	X:	-.07099	-.07325	-.06076	-.05960
	t:	-2.163	-2.190	-1.924	-1.792
Fdelay3	X:	+.08646	-.08459	+.07115	+.07177
	t:	+2.483	-2.310	+1.926	+1.903
TGap	X:		+1.49726	+1.4793	+1.47445
	t:		+35.262	+35.499	+35.585
Speed	X:	-.07769	+.02753		
	t:	-14.987	+5.952		
SGap	X:	+.08324			
	t	+35.004			
Type-P	X:	-1.22547	-.49885	+.16837	
	t:	-1.978	-.587	+.198	
Type-T/B	X:	-1.30948	-.63374	-.05817	
	t:	-1.982	-.718	-.066	
Type-M	X:	-2.50938	-1.60705	-.78073	
	t:	-2.409	-1.399	-.694	
Flow	X:	+.19084	+.11765	+.11758	+.119020
	t:	+12.619	+13.067	+13.220	+13.420
VehBeh	X:	+.23333	+.24418	+.23875	+.24517
	t:	+1.861	+1.955	+1.922	+1.981
99St	X:	-.98536	-.91349	-.73816	-.78472
	t:	-4.805	-4.145	-3.402	-3.642
KE	X:	-.41094	-.33918	+.11192	+.06568
	t:	-2.237	-1.752	+.633	+.375
WE	X:	-.06099	+.02945	+.15716	+.14413
	t:	-.355	+.157	+.851	+.788
SP	X:	-2.37715	-1.74051	-.71522	-.76090
	t:	-8.119	-6.205	-3.281	-3.522

Table 6.7 (cont.....)

Models Statistics:

Model #	1	2	3	4
LL(0)	-4425.0516	-4425.0516	-4425.0516	-4425.0516
LL(β)	-1372.2546	-1362.6554	-1380.7538	-1389.0233
$\rho^2(0)$	0.690	0.6921	0.688	0.686
$\rho^2(0)$(Aic)	0.685	0.687	0.683	0.683
%correct	87.12	87.22	87.03	86.93

Model 1: Space gap+speed
Model 2: Time gap+speed
Model 3: Time Gap
Model 4: Time Gap (excluding Age, Acc.Cap., and Type)

Following the previous discussion, it was decided to try excluding the speed from model 2. The result is presented as Model 3 in Table 6.7 . Excluding the speed led to the following results:

- All coefficient estimates have signs which were logical.

- All coefficient estimates except for age, acceleration capability, type of opposing vehicle and location specific constant (Keillor Road and WEM intersections) are statistically different from zero.

Using the likelihood ratio statistics to test the null hypothesis that Model 2 and Model 3 are equal:

X^2 = -2 [-1380.7538+1362.6554] = 36.2

X^2 value for 1 degree of freedom and 95% confidence level = 3.84

Therefore, the null hypothesis, that the two models are equal, could be rejected.

The modified likelihood ratio index for Model 2 (time gap + speed model) is slightly higher than that for model 3 (time gap model). The difference between the two indices (0.004) is lower than 0.01 indicating that both models fit the data equally.

Comparing Model 1 and Model 3, coefficient estimates for type of opposing vehicles are statistically different from zero at 90% level of confidence, if space gap is included in the model (Model 1), and are not different from zero, if time gap is included in the model. The previous results could be explained as the effect of time gap might capture the effect of space gap (distance), speed, and type of opposing vehicle.

Model 4, same as model 3 except excluding all non significant variables[1]; age, acceleration capability and type of opposing vehicles. Excluding these variables led to the following results:

- All coefficients had signs which were consistent with what was expected.

Using the likelihood ratio statistics to test the null hypothesis that the coefficient estimates for age and acceleration capability and type of opposing vehicle are equal to zero:

$X^2 = -2\ [-1389.0233+1380.7538] = 16.54$

X^2 value for 7 degree of freedom and 95% confidence level = 14.07

Therefore, the null hypothesis can be rejected. Thus, it was decided not to exclude these variables from the model.

Comparing Model 1 with Model 3 in the Table 6.7, it can be concluded that:

The modified likelihood ratio index $\rho^2(0)$(Aic) for the space gap and speed model (Model 1) is slightly higher than that for the time gap model (Model 3). The difference between the indices (0.685 - 0.683 = 0.002) is less than 0.01. Therefore the two models are considered to fit the data equally.

The previous results could not confirm whether drivers perceive distance gap and speed or time gap. Since both models fit the data equally, the model with the slightly higher modified likelihood ratio index (space gap and speed model) was selected for any further investigation.

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[1]It was decided before not to exclude the age and acceleration capability variables from the model 1 (based on the results of comparing Model 2 and Model 3 in Table 6.4).

6.6 INVESTIGATION OF BEHAVIOUR DURING PEAK HOURS AND OFF-PEAK HOURS

The "best" model specification (Model 1 in Table 6.7) was used to examine the change in the behaviour between peak and off-peak periods. The results of models estimations are shown in Table 6.8. Model 1 was estimated using all peak-hour data. Model 2 was estimated using peak-hour data for only WEM, and Keillor Road locations in order to compare its result with model 3 that used off-peak hour data. Off-peak hour data were collected only at WEM and Keillor Road locations. Summary of the average value of the variables used for model estimations for peak and off-peak data are given in Table 6.9.

In Model 1, all coefficients had signs which were logical. For front delay equal to or less than 30 seconds, as front delay increases, the probability of accepting a gap decreases. For front delay greater than 30 seconds as front delay increases, the probability of accepting a gap increases. All coefficient estimates except type of opposing vehicle (P, T/B) and location specific constant for WEM are different from zero at 90% level of confidence.

The sign of the coefficient estimates and their significance in Model 2 were the same as in Model 1. The values of the coefficient estimates of Model 2 (WEM, KE PM peak hour data) were slightly different from those in Model 1 (all peak hours data).

When estimating the coefficients of Model 3 (off-peak hour model) for the first time, the model did not converge. When checking the values of the coefficient and the average value of each parameter (usually the coefficient with the highest value is suspected), it was found that Fdelay3 coefficient has a very high value. The average value of Fdelay3 parameters was found to be almost zero (exactly .0026 second) which meant that almost no vehicles were delayed more than 30 seconds. With the exclusion of Fdelay3, the model converged. The results are shown as Model 3 in Table 6.8. The results showed that, for Fdelay less than or equal to 15 seconds, as Fdelay increases, the probability of accepting a gap decreases. For Fdelay greater than 15 seconds as Fdelay increases, the probability of accepting a gap increases but the coefficient was not statistically different from zero (t-ratio = +.835). All other coefficients except type of opposing vehicles, vehicle behind and location specific constant for Keillor Road were different from zero at 90% level of confidence.

Table 6.8 Peak Versus Off-Peak Hours Model

Model #		1	2	3
Parameters				
Constant	X: t:	-2.6695 -3.702	-2.6942 -2.644	-3.5692 -3.328
Gender	X: t:	+.6480 +5.654	+.6010 +3.886	+.8054 +3.040
Age-Y		+.3501 +1.296	-.3111 -.844	+.0787 +.123
Age-M		-.0330 -.131	-.4910 -1.432	-.8803 -1.465
Pass	X: t:	-.3719 -3.110	-.4235 -2.600	-.6902 -2.437
Acc-L		-.1825 -.755	-.2722 -.887	+.1011 +.183
Acc-A		-.1870 -.801	-.1879 -.639	+.2753 +.528
Qdelay	X: t:	+.0264 +3.955	+.0218 +2.653	+.05651 +1.652
Fdelay1	X: t:	-.1239 -8.081	-.1439 -6.648	-.2503 -5.489
Fdelay2	X: t:	-.0801 -2.395	-.1186 -2.319	+.1174 +.835
Fdelay3	X: t:	+.0901 +2.576	+.1472 +3.260	
Speed	X: t:	-.0725 -13.204	-.0827 -10.922	-.1184 -7.514
SGap	X: t	+.0804 +31.725	+.0888 +23.185	+.0994 +14.301
Type-P	X: t:	-.9074 -1.289	-.9301 -.937	-.4159 -.469
Type-T/B	X: t:	-.8695 -1.158	-1.2662 -1.171	-.8749 -.856
Type-M	X: t:	-2.1501 -1.732	-1.7265 -1.068	
Flow	X: t:	+.0967 +10.426	+.1052 +7.383	+.2077 +7.477
VehBeh	X: t:	+.2883 +2.138	+.2439 +1.335	+.1139 +.329
99St	X: t:	-.9677 -4.745		
KE	X: t:	-.4940 -2.531	-.4112 -2.300	+.0715 +.229
WE	X: t:	-.0432 -.244		
SP	X: t:	-2.4531 -8.218		

Table 6.8 (Cont...)

Models Statistics:

Model #	1	2	3
LL(0)	-3618.921	-1946.3573	-806.1301
LL(β)	-1155.756	-604.9833	-213.3703
$\rho^2(0)$	0.6806	0.6891	0.7353
$\rho^2(0)$(Aic)	0.6757	0.6814	0.7192
%correct	86.749	87.05	88.915
Alternative 1 occurs: (%)	1846 (35.36)	1020 (36.32)	488 (41.96)
Alternative 2 occurs: (%)	3375 (64.64)	1788 (63.68)	675 (58.04)
Total number of observations :	5221	2808	1163

Model 1: Peak hours (all data)
Model 2: Peak hours (WEM, Keillor Road locations)
Model 3: Off-Peak hours (WEM, Keillor Road locations)

Table 6.9 Average Value of Variables Used for Model Estimations Described in Table 6.8

Variable		Peak hours (All locations)	Peak hours (KE, WE)	Off-peak (KE,WE)
Gender-M	(%)	60.5	58.6	57.2
Age-Y	(%)	22.6	23.6	21.8
Age-M	(%)	71.8	71.4	72.7
Pass	(%)	30.5	32.6	35.5
Acc-L	(%)	30.6	30.9	33.7
Acc-A	(%)	64.4	62.0	59.9
Qdelay	(s)	4.05	4.47	1.67
Fdelay1	(s)	4.79	4.60	3.13
Fdelay2	(s)	.94	.77	.24
Fdelay3	(s)	.29	.22	.003
Sgap	(m)	83.80	79.16	87.47
TypeP	(%)	95.9	96.2	94.3
TypeT/B	(%)	3.1	2.8	4.5
TypeM	(%)	0.6	0.7	0.7
Speed	(km/h)	66.87	65.94	63.65
#Rej		3.06	2.60	1.57
Flow	(veh/min)	16.76	16.74	12.99
VehBeh	(%)	37.8	39.7	26.0

Comparing Model 2 (KE, WE PM peak hours data) with model 3 (KE, WE off-peak hours), it was found that the location specific constant was statistically different from zero during the peak hour, while it was not different from zero in the off-peak model. One possible explanation for this result is that peak-hour drivers might be more familiar with intersections than off-peak drivers. Another explanation might be that traffic conditions during off peak is similar at these two locations (low flow rate) while it is different in the peak-hour period (higher flow rate).

6.7 INVESTIGATION OF QUEUE DELAY AND FRONT DELAY IMPACT

The best model specification so far (Model 1 in Table 6.7), was used to investigate the impact of different experiences of queue delay and front delay as follows:

Model 1: Include Qdelay; No Fdelay

This case included drivers who had to wait in a queue because there were vehicles in front of them, and once they became first in the queue, they did not have to wait and accepted the first gap (lag) presented.

Model 2: Include Qdelay ; Fdelay

This case included drivers who had to wait in a queue because there were vehicles in front of them, and when they became first vehicle in the queue, they had to wait for a suitable gap.

Model 3: No Qdelay; Fdelay

This case included drivers who arrived at the intersection and there were no vehicles waiting, but they had to stop for a suitable gap.

Model 4: No Qdelay; No Fdelay

This case included drivers who arrived at the intersection, there was no queue, they did not have to wait at the intersection and accepted the first gap (lag).

All four models are shown in Table 6.10. In all models, there was a convergence problem. This problem was due to the decrease in sample size and consequently decreases in the number of cases involving motorcycles as opposing vehicles. It was therefore

decided to split type of the opposing vehicles into passenger vehicles, trucks or buses, and others (including bicycles and motorcycles).

In case of experiencing front delay (Models 2, 3) Location Specific constants were found to be highly significant. In case of experiencing no front delay (Models 1, 4), location Specific constants (except for Stony Plain Location) were not statistically different from zero.

6.7.1 Comparison of Experiencing Queue Delay and Front Delay to No Delay

Comparing Model 2 (Qdelay + Fdelay) to Model 4 (neither Qdelay nor Fdelay), the following are the results:

- In Model 2 all coefficient estimates except VehBeh coefficient had signs which were consistence with what was expected. The VehBeh coefficient was not statistically different from zero (t-ratio = -.009). Other coefficient estimates except age, acceleration capability, existence of passenger, Qdelay, and Fdelay2, Fdelay3, and type of opposing vehicles were statistically different from zero. Acc-A, Qdelay, and Fdelay2 coefficients were judged as acceptable (t-ratios were -1.314, +1.247 and -1.532). Insignificance of many coefficient estimates might be due to the decrease in the sample size due to segmentation of data (only 872 cases experienced both Qdelay and Fdelay out of 6384 cases. Regarding type of opposing vehicle, the probability of accepting a gap increases in the following order: motorcycle and bicycle, truck or bus, and Passenger vehicle. Type "Others" included more motorcycles than bicycles (only 7 motorcycles and 1 Bike).

-Model 4 represents results of choice situations for drivers who did not experience any Qdelay or Fdelay. Coefficient estimates for existence of passengers had an expected sign and was statistically different from zero (t-ratio= 2.96). This was opposite to the result of Model 2 (t-ratio was -0.04). All coefficients except VehBeh had signs which were consistent with what was expected. The VehBeh coefficient estimate was statistically not different from zero (t-ratio=-.596). This result regarding vehicles behind could possibly be explained by the fact that drivers who did not stop at the intersection and accepted the first gap presented, were not under pressure of the vehicles behind them (only in 23 choice situations, there were vehicles behind out of 1818 situations). All other coefficient estimates except Age-Y, acceleration capability, type of opposing vehicle and location specific constants (99 St, and KE) were statistically different from zero.

Table 6.10 Effect of Different Experience of Queue Delay and Front Delay

Model #		1	2	3	4
Parameters					
Constant	X:	-3.1397	-8.3326	-4.1948	-2.9547
	t:	-2.412	-3.070	-4.213	-3.953
Gender	X:	+.6883	+.8204	+.4591	+.9095
	t:	+3.258	+2.232	+2.417	+4.847
Age-Y	X:	+.4266	+.1276	+.3721	+.0753
	t:	+.701	+.082	+.880	+.190
Age-M	X:	-.2112	+.0780	+.1840	-.6599
	t:	-.364	+.050	+.478	-1.782
Pass	X:	-.3170	-.0164	-.5435	-.5603
	t:	-1.419	-.040	-2.718	-2.959
Acc-L	X:	+.2056	-.3302	+.2905	-.5304
	t:	+.450	-.363	+.661	-1.532
Acc-A	X:	+.3954	-1.1818	-.0584	-.0731
	t:	+.907	-1.314	-.137	-.222
Qdelay	X:	+.0088	+.0194		
	t:	+.843	+1.247		
Fdelay	X:				
	t:				
Fdelay1	X:		-.1023	-.0394	
	t:		-1.963	-1.532	
Fdelay2	X:		-.1669	-.1392	
	t:		-1.532	-3.339	
Fdelay3	X:		+.0964	+.1330	
	t:		+.928	+3.247	
Speed	X:	-.0774	-.0614	-.0975	-.0725
	t:	-7.003	-3.111	-10.119	-8.500
SGap	X:	+.0755	+.1119	+.0897	+.0771
	t	+14.222	+11.069	+21.122	+19.265
Type-P	X:	+.3179	+1.4754	+.1865	-.5867
	t:	+.280	+.630	+.216	-.903
Type-T/B	X:	+.0125	+1.7593	+.3977	-.9643
	t:	+.010	+.722	+.414	-1.239
Type-M	X:				
	t:				
Flow	X:	+.1210	+.1892	+.1495	+.0692
	t:	+5.437	+4.706	+10.444	+4.498
VehBeh	X:	+.0174	-.0036	+.1847	-.4628
	t:	+.079	-.009	+.910	-.596
99St	X:	-.2499	-3.1734	-2.0065	-.0459
	t:	-.497	-3.756	-5.935	-.132
KE	X:	-.00999	-2.6602	-.6536	-.0681
	t:	-.023	-3.485	-2.046	-.233
WE	X:	-.2684	-1.2638	-.8213	+.7824
	t:	-.651	-1.931	-2.736	+2.864
SP	X:	-1.7016	-4.8332	-2.5878	-2.3719
	t:	-2.768	-4.282	-4.504	-4.693

Table 6.10 (cont...)

Model Statistics:

Model #	1	2	3	4
LL(0)	-713.248	-604.4243	-1847.237	-1260.142
LL(β)	-307.034	-114.016	-428.944	-447.133
LL(c)	-680.812	-537.170	-1469.089	-1242.898
$\rho^2(0)$	0.564	0.807	0.767	0.637
$\rho^2(0)$(Aic)	0.545	0.779	0.758	0.627
$\rho^2(c)$(Aic)	0.575	0.827	0.722	0.654
%correct	81.44	92.52	90.65	85.14
Alternative 1 occurs: (%)	643 (62.49)	267 (30.62)	640 (24.02)	784 (43.12)
Alternative 2 occurs: (%)	386 (37.51)	605 (69.38)	2025 (75.98)	1034 (56.88)
Total number of observations :	1029	872	2665	1818

Model 1: Include Qdelay; No Fdelay
Model 2: Include Qdelay ; Fdelay
Model 3: No Qdelay; Fdelay
Model 4: No Qdelay; No Fdelay

Regarding type of opposing vehicle, the probability of accepting a gap increases in the following order: truck or bus, passenger vehicle, and "others". In this model type "others" had a higher probability of accepting than passenger vehicle, truck and bus. This was opposite to the finding in Model 2. One possible explanation is that in Model 4, the number of choices involving bicycles was higher than those which involved motorcycles, making bicycles dominate the effect (13 bicycles to 10 motorcycles). This result indicated that combining motorcycles and bicycles was not a good idea since they represent both extremes.

6.7.2 Comparison of Experiencing Queue Delay to Front Delay

Comparing Model 1 (Qdelay only) to Model 3 (Fdelay only), gives the following results:

- Model 1 represents choice situations for drivers who have been delayed only in a queue (no front delay). All coefficients had signs which were consistent with what was expected. Coefficient estimates for Gender, Speed, Sgap, Flow, Location Spec. Constant(SP) were statistically different from zero. Coefficient estimates for age, presence of passengers, acceleration capability, Qdelay, type of opposing vehicle, VehBeh, and location specific constant (99, KE,WE) were not statistically different from zero. Regarding the type of opposing vehicle, the probability of accepting a gap increases in the following order: others, truck or bus, passenger vehicle.

- Model 3 represents choice situations for drivers who have been delayed only in the front of a queue. All coefficients had signs which were consistent with what was expected. All other coefficients except Age, Acc., Fdelay1, Type of opposing vehicle were statistically different from zero. Regarding type of opposing vehicle, the probability of accepting a gap increases in the following order: others, passenger vehicle, and truck or bus which was illogical, but coefficients of the type of opposing vehicle were not statistically different from zero.

6.8 INVESTIGATION OF NUMBER OF LANES, APPROACH WIDTH, AND LOCATION SPECIFIC CONSTANT

This section examines the effect of location geometry on a driver gap acceptance. Based on Model 1 in Table 6.7, several utility functions were examined, as shown in Table 6.11. Model 1 included the number of lanes variable, Model 2 included approach width, and model 3 included location specific constants. Based on the results of these model estimations, it was decided to include number of lanes and location specific constants for the 99 Street and WEM locations since they both have the same number of lanes. The results of these model estimations are discussed as follows:

Table 6.11 Investigation of Approach Width, Number of Lanes, and Location Specific Constants

Model #		1	2	3	4
Parameters					
Constant	X:	-.88866	-.91316	-2.34542	-.42218
	t:	-1.287	-1.317	-3.364	-.603
Gender	X:	+.6541	+.64726	+.71005	+.70096
	t:	+6.235	+6.182	+6.668	+6.597
Age-Y	X:	+.31113	+.31319	+.30243	+.27881
	t:	+1.285	+1.294	+1.229	+1.136
Age-M	X:	-.14019	-.14453	-.16151	-.16110
	t:	-.621	-.641	-.705	-.705
Pass	X:	-.35681	-.36167	-.38855	-.39541
	t:	-3.295	-3.341	-3.533	-3.601
Acc-Low	X:	-.22723	-.23039	-.12458	-.16302
	t:	-1.048	-1.063	-.570	-.751
Acc-Ave	X:	-.14915	-.12753	-.08806	-.12771
	t:	-.714	-.610	-.419	-.612
Qdelay	X:	+.02875	+.02823	+.02980	+.31063
	t:	+4.435	+4.355	+4.525	+4.730
Fdelay1	X:	-.13739	-.13610	-.13516	-.13575
	t:	-9.633	-9.589	-9.278	-9.326
Fdelay2	X:	-.08705	-.08716	-.07099	-.06866
	t:	-2.745	-2.751	-2.163	-2.100
Fdelay3	X:	+.08292	+.08121	+.08646	+.08654
	t:	+2.387	+2.343	+2.483	+2.489
Speed	X:	-.07656	-.07977	-.07769	-.07553
	t:	-15.184	-16.259	-14.987	-14.783
Sgap	X:	+.08145	+.08132	+.08324	+.08293
	t:	+35.244	+35.265	+35.004	+35.010
Type-P	X:	-1.29380	-1.23815	-1.22547	-1.29473
	t:	+2.104	-2.011	-1.978	-2.108
Type-T/B	X:	-1.42664	-1.37647	-1.30948	-1.37279
	t:	-2.172	-2.094	-1.982	-2.095
Type-M	X:	-2.59016	-2.53313	-2.50938	-2.54594
	t:	-2.582	-2.535	-2.409	-2.463
Flow	X:	+.09640	+.09670	+.19084	+.11120
	t:	+12.067	+12.136	+12.619	+12.936
VehBeh	X:	+.27364	+.24754	+.23333	+.24152
	t:	+2.208	+2.006	+1.861	+1.928
#lanes	X:	-.58615			-.83732
	t:	-7.328			-8.729
Width	X:		-.12882		
	t:		-6.915		
99St	X:			-.98536	-1.27289
	t:			-4.805	-7.274
KE	X:			-.41094	
	t:			-2.237	
WE	X:			-.06099	-.32587
	t:			-.355	-2.326
SP	X:			-2.37715	
	t:			-8.119	

Table 6.11 (cont....)

Models Statistics:

Model #	1	2	3	4
LL(0)	-4425.05	-4425.05	-4425.0516	-4425.0516
LL(β)	-1404.17	-1407.37	-1372.25	-1375.97
$\rho^2(0)$	0.683	0.682	0.690	0.690
$\rho^2(0)$(Aic)	0.6783	0.6777	0.685	0.685
%correct	86.80	86.77	87.12	87.09

Model 1: Includes number of lanes
Model 2: Includes approach width
Model 3: Includes location specific constants
Model 4: Includes number of lanes and location specific constant for 99 street and WEM intersections

1- Values and significance of the coefficient estimates for variables other than number of lanes, approach width, and location specific constants remained almost unchanged for different model specification.

2- Model 1, which included the number of lanes, had a slightly higher likelihood ratio index $\rho^2(0)$(Aic) than that for Model 2 which included approach width. The difference between the two indices was less than 0.01 which indicated that both models fit the data equally.

3- Model 3 which included location specific constants, had a higher likelihood ratio index $\rho^2(0)$(Aic) than those of Models 1, 2 which included either number of lanes or approach width. The difference between those indices was less than 0.01 indicating that the three functions fit the data equally.

4- Since all models fit the data equally, it was decided to include the number of lanes as well as location specific constants for 99 Street and WEM locations since these two locations have the same number of lanes. This model specification is shown as Model 4 in Table 6.11. The results showed that the coefficient estimates for the number of lanes and location specific constants were all statistically different from zero at 90% level of confidence. This model specification was used in any further investigations.

6.9 FURTHER INVESTIGATION OF FRONT DELAY

In Section 6.3, splitting the front delay variable into three variables confirmed the non-linearity effect of front delay. Since the number of front delay variables and their ranges were chosen arbitrarily, as an initial step, it was decided to study this point in detail. The steps followed until the final model had evolved are described in detail when discussing the results of the estimated functions. These functions, shown in Tables 6.12 and 6.13, are based on Model 4 in Table 6.11.

Model 1 includes front delay as a binary variable to investigate the effect of stopping and not stopping at the intersection on the gap acceptance. Front delay variable (Fdelay/N0) was coded as follows:

Fdelay/No = 1 if driver had to stop (with front delay)
= 0 if driver did not stop, (no front delay)

-Model 1 showed that the probability of accepting a gap for drivers who were delayed at the front of the queue (who had to stop), was lower than that for drivers who did not stop. The coefficient estimate for this variable was statistically different from zero. The model can not explain if different values of front delay would have different effects on gap acceptance.

- To study the effect of different ranges of front delay in detail, it was decided to divide front delay into 10 variables of 5 second increments. The result of that model specification is shown as Model 2 (Table 6.12). The result showed that this model has a slightly higher likelihood ratio index $\rho^2(0)$(Aic), than that for the model that included front delay as three arbitrary variables. The signs and the values of the coefficient estimate of Fdelay showed a fluctuation in behaviour which was expected because of the very short intervals which led to a decrease in data size in some of the intervals.

Table 6.12 Different Model Specifications for Further Investigation of Front Delay (Part 1)

Model #		1	2	3	4	5	6
Parameters							
Constant	X:	-.21333	-.38266	-.38316	-.37880	-.37037	-.37128
	t:	-.307	-.544	-.545	-.539	-.527	-.528
Gender	X:	+.70720	+.70523	+.70671	+.70659	+.70336	+.70564
	t:	+6.707	+6.592	+6.607	+6.611	+6.579	+6.602
Age-Y	X:	+.22105	+.25252	+.25423	+.24794	+.25292	+.24998
	t:	+.906	+1.022	+1.030	+1.005	+1.025	+1.013
Age-M	X:	-.21913	-.17835	-.17583	-.17832	-.17451	-.17596
	t:	-.963	-.775	-.765	-.776	-.759	-.766
Pass	X:	-.45041	-.42340	-.42473	-.42158	-.42320	-.42275
	t:	-4.134	-3.816	-3.832	-3.806	-3.818	+3.814
Acc-Slow	X:	-.17619	-.15855	-.15865	-.15727	-.15617	-.15375
	t:	-.804	-.723	-.724	-.718	-.712	-.701
Acc-Ave	X:	-.17361	-.12308	-.12540	-.12402	-.12306	-.12357
	t:	-.825	-.584	-.596	-.589	-.584	-.587
Qdelay	X:	+.03431	+.02985	+.02985	+.02983	+.02995	+.02987
	t:	+5.230	+4.480	+4.482	+4.482	+4.504	+4.494
Fdelay/No =1if delayed	X:	-1.25670					
	t:	-10.902					
Fdelay0-	X:		-.31486	-.31221	-.30430	-.30642	-.30708
	t:		-8.860	-8.849	-9.656	-9.355	-9.377
Fdelay1.5-	X:						
	t:						
Fdelay5-	X:		+.028780	+.01252	-.01028	-.00112	-.00058
	t:		+.503	+.238	-.497	-.039	-.020
Fdelay10-	X:		-.072190	-.02162			
	t:		-.831	-.513			
Fdelay15-	X:		+.02959			-.09544	-.10081
	t:		+.229			-1.685	-1.788
Fdelay20-	X:		-.23480	-.30139	-.25657		
	t:		-1.236	-2.912	-4.015		
Fdelay25-	X:		-.60148			-.49416	-.34500
	t:		-1.574			-2.058	-2.094
Fdelay30-	X:		+.58401	+.31886	+.13496	+.25762	+.13690
	t:		+1.382	+1.147	+3.609	+1.819	+3.360
Fdelay35-	X:		+.02454	+.09406			
	t:		+.074	+.365			
Fdelay40-	X:		+.14755	+.11139		+.09433	
	t:		+.446	+1.686		+1.489	
Fdelay45-	X:		+.10606				
	t:		+1.090				

Table 6.12 (cont....)

Model #		1	2	3	4	5	6
Parameters							
Speed	X:	-.07541	-.07752	-.07754	-.07765	-.07753	-.07763
	t:	-14.793	-14.984	-15.000	-15.018	-14.989	-15.009
Sgap	X:	+.81927	+.08386	+.08386	+.08385	+.08375	+.08375
	t:	+35.012	+34.672	+34.697	+34.719	+34.744	+34.741
Type-P	X:	-1.15800	-1.20229	-1.20132	-1.20127	-1.20322	-1.20209
	t:	-1.896	-1.954	-1.953	-1.953	-1.953	-1.952
Type-T/B	X:	-1.15515	-1.23037	-1.2348	-1.23974	-1.23938	-1.24360
	t:	-1.768	-1.869	-1.877	-1.885	-1.882	-1.889
Type-M	X:	-2.26541	-2.33837	-2.35713	-2.35808	-2.37098	-2.36137
	t:	-2.292	-2.303	-2.324	-2.321	-2.338	-2.326
Flow	X:	+.10751	+.11912	+.11907	+.11911	+.11857	+.11878
	t:	+12.621	+13.538	+13.545	+13.557	+13.497	+13.526
VehBeh	X:	+.09228	+.28172	+.28417	+.28494	+.27812	+.28051
	t:	+.765	+2.222	+2.243	+2.251	+2.195	+2.215
#lanes	X:	-.81988	-.84043	-.84093	-.84019	-.83936	-.83841
	t:	-8.602	-8.701	-8.707	-8.705	-8.694	-8.685
99St	X:	-1.45739	-1.31804	-1.31893	-1.3180	-1.32101	-1.31605
	t:	-8.419	-7.471	-7.480	-7.485	-7.494	-7.474
WE	X:	-.36391	-.33705	-.33480	-.33749	-.33858	-.33854
	t:	-2.604	-2.385	-2.370	-2.390	-2.397	-2.397

Models statistics

Model #	1	2	3	4	5	6
LL(0)	-4425.05	-4425.05	-4425.05	-4425.05	-4425.05	-4425.05
LL(β)	-1384.12	-1355.03	-1355.60	-1356.06	-1356.08	-1356.49
$\rho^2(0)$	0.687	0.694	0.694	0.694	0.6935	0.6935
$\rho^2(0)$(Aic)	0.683	0.688	0.688	0.689	0.6881	0.6883
%correct	87.02	87.30	87.29	87.29	87.30	87.29

Model 1 : Includes binary variable for front delay
Model 2 : Includes front delay as 10 intervals of 5 seconds each
Model 3 : Combining some of Fdelay intervals depends on result of t-test shown in Table D.1
Model 4 : Combining some of Fdelay intervals depends on result of t-test shown in Table D.2
Model 5 : Combining some of Fdelay intervals depends on result of t-test shown in Table D.1
Model 6 : Combining some of Fdelay intervals depends on result of t-test shown in Table D.3

Table 6.13 Different Model Specifications for Further Investigation of Front Delay (Part 2)

Model #		7	8	9	10	11
Parameters						
Constant	X:	-.40133	-.39962	-.40178	-.39725	-8.4361
	t:	-.573	-.571	-.574	-.568	-8.962
Gender	X:	+.70681	+.70571	+.70727	+.70714	+.68973
	t:	+6.597	+6.592	+6.606	+6.604	+6.494
Age-Y	X:	+.26096	+.25889	+.26236	+.25688	+.24818
	t:	+1.054	+1.047	+1.062	+1.040	+.994
Age-M	X:	-.17467	-.17596	-.17333	-.17562	-.14626
	t:	-.758	-.763	-.753	-.763	-.629
Pass	X:	-.43263	-.43227	-.43478	-.43338	-.45502
	t:	-3.892	-3.891	+3.918	-3.907	-4.096
Acc-Slow	X:	-.12910	-.12936	-.12596	-.12433	-.14582
	t:	-.586	-.587	-.572	-.564	-.658
Acc-Ave	X:	-.10737	-.10765	-.11000	-.10957	-.10527
	t:	-.507	-.508	-.520	-.518	-.494
Qdelay	X:	+.02880	+.02879	+.02874	+.02871	+.02732
	t:	+4.295	+4.295	+4.291	+4.288	+4.156
Fdelay0-	X:	-.78442	-.78855	-.81808	-.81392	-.84057
	t:	-5.874	-7.900	-8.577	-8.555	-8.837
Fdelay1.5-	X:	-.05516	-.05427	-.04169	-.04347	-.04620
	t:	-.702	-2.560	-2.551	-2.693	-2.855
Fdelay5-	X:	-.06175				
	t:	-.991				
Fdelay10-	X:	-.03719				
	t:	-.425				
Fdelay15-	X:	+.01431	+.03003			
	t:	+.111	+.283			
Fdelay20-	X:	-.23277	-.24267	-.27384	-.22842	-.22776
	t:	-1.221	-1.296	-2.968	-3.691	-3.666
Fdelay25-	X:	-.60576	-.57749			
	t:	-1.579	-1.556			
Fdelay30-	X:	+.59136	+.52683	+.28122	+.13215	+.11970
	t:	+1.394	+1.471	+1.270	+3.530	+3.024
Fdelay35-	X:	+.01692	+.10511	+.11103		
	t:	+.051	+2.126	+2.272		
Fdelay40-	X:	+.15142				
	t:	+.457				
Fdelay45-	X:	+.10883				
	t:	+1.117				
Tgap	X:					+1.49816
	t:					+35.116

Table 6.13 (cont...)

Model #		7	8	9	10	11
Parameters						
Speed	X:	-.07743	-.07739	-.07730	-.07740	
	t:	-14.949	-14.959	-14.958	-14.976	
Sgap	X:	+.08421	+.08419	+.08414	+.08412	
	t:	+34.597	+34.616	+34.648	+34.654	
Type-P	X:	-1.18564	-1.1849	-1.18392	-1.18198	+.28436
	t:	-1.937	-1.936	-1.936	-1.933	+.347
Type-T/B	X:	-1.20280	-1.20234	-1.20911	-1.21196	+.11517
	t:	-1.834	-1.833	-1.846	-1.850	+.135
Type-M	X:	-2.35236	-2.34693	-2.35575	-2.3489	-.54500
	t:	-2.334	-2.331	-2.347	-2.338	-.503
Flow	X:	+.12458	+.12452	+.12442	+.12445	+.13428
	t:	+13.874	+13.903	+13.909	+13.914	+14.568
VehBeh	X:	+.27809	+.27693	+.27492	+.27500	+.28283
	t:	+2.189	+2.181	+2.170	+2.171	+2.252
#lanes	X:	-.85718	-.85709	-.85721	-.85603	-.31119
	t:	-8.842	-8.850	-8.851	-8.842	-4.465
99St	X:	-1.33117	-1.33336	-1.33118	-1.33027	-1.1035
	t:	-7.521	-7.540	-7.531	-7.528	-6.139
WE	X:	-.33247	-.33232	-.32895	-.33084	-.13316
	t:	-2.349	-2.348	-2.325	-2.339	-.917

Models statistics

Model #	7	8	9	10	11
LL(0)	-4425.05	-4425.05	-4425.05	-4425.05	-4425.0516
LL(β)	-1348.19	-1348.25	-1349.02	-1349.25	-1355.8749
ρ2	0.6953	0.6953	0.6951	0.6951	0.6936
ρ2(Aic)	0.6888	0.6897	0.6899	0.6901	0.6888
%Correct	87.37	87.37	87.37	87.37	87.27

Model 7: Same as Model 2 except dividing Fdelay 0-5 sec into 2 variables (0-1.5) & (1.5-5)
Model 8 : Combination of Fdelay variables according to results of t-test shown as in Table D.4
Model 9 : Combination of Fdelay variables according to results of t-test shown in Table D.5
Model 10: Combination of Fdelay variables according to results of t-test shown in Table D.6
Model 11: Same as Model 10 except using time gap instead of space gap and speed

Testing the linear relationship between Fdelay variables of Model 2 using variance-covariance matrix information as shown in Table D.1 (Appendix D), some front delay variables could be combined as follows:

F10-15 and F15-20

F20-25 and F25-30

F40-45 and F>45 This combination was tried as Model 3 in Table 6.12.

The result showed that Model 3 has a slightly higher likelihood ratio index [$\rho^2(0)$(Aic)] than Model 2. The difference between the two indices is less than 0.01 indicating that both models fit the data equally. Using the likelihood ratio test also showed that the two models are equal. The sign of front delay parameter F 5-10 (Positive sign) is not consistent with the previous results of analyzing front delay (as three variables). It is also not consistent with the signs of the previous and following front delay variables (F0-5 and F10-20 have negative sign). F5-10 coefficient estimate is not statistically different from zero. F30-35 and F35-40 coefficient estimates are also not statistically different from zero but their signs were consistence with what was expected.

Testing the linear relationship between Fdelay variables of Model 3 using variance-covariance matrix information as shown in Table D.2 (Appendix D), some front delay variables could be combined as follows:

F5-10 and F10-20

F30-35, F35-40 and F>40

Other possible combinations, depending on the same test, are as follows:

F5-10 and F10-F15

F15-20 and F20-F25

F30-35 and F35-40

These two combination were tried as Models 4 and 5 in Table 6.12.

The result showed that the likelihood ratio indices, for Models 3, 4, and 5, are almost equal (the differences <0.01) indicating that all three models fit the data equally. Likelihood ratio test also proved that Models 3, 4 and 5 are equal. In Model 4 signs of all front delay parameters are consistent with what is expected and only F5-20 coefficient estimate is not statistically different from zero. In Model 5, all front delay parameters

have signs which are as expected and their coefficient estimates, except for F0-15, and F>40, are statistically different from zero.

Testing the linear relationship between Fdelay variables of Model 5 (Table 6.12) using variance-covariance matrix information as shown in Table D.3 (Appendix D), the following combination of front delay variables is possible:

F30-40 and F>40 This combination has been tried as in Model 6 in Table 6.12.

The results showed that the likelihood ratio index for Model 6 is almost the same as Models 2, 3,4, and 5. The likelihood ratio test indicated that Model 6 and the other Models (Models 2, 3, 4, 5) fit the data equally. In Model 6, all coefficient estimates, for front delay variables, have signs that are as expected and all, except F5-15 coefficient estimate, are statistically different from zero.

To account for the variation in behaviour between stopping and non stopping situations, it was decided to divide the first front delay interval into two intervals as follows:

F0-1.5 to account for non stopping
F1.5-5 to account for stopping and delaying

The result is shown as Model 7 in Table 6.13. Model 7 is the same specification as Model 2 in Table 6.12 except that the first Fdelay interval (0-5 s) is divided into two intervals (0-1.5, and 1.5-5 s). The result showed that the likelihood ratio index $\rho^2(0)$(Aic) is slightly higher than Model 2.

The variance-covariance matrix information was used to test the linear relationship between Fdelay variables of Model 7 as shown in Table D.4. The result of this test showed that the relationship between the coefficients for F0-1.5 and F1.5-5 is nonlinear, therefore, they can not be combined as one variable. Regarding other front delay intervals the following combination is possible:

F1.5 -5 , F5-10, and F10-15
F35-40, F40-45, and F>45 This combination is shown as Model 8 in Table 6.13.

The previous step was repeated and the results of the statistical tests are shown in Table D.5, and D.6. The result of model estimations are presented as Models 9, and 10 in Table 6.13.

Likelihood ratio test indicated that all four models, 7, 8, 9, and 10, are equal. Since Model 10 has a slightly higher likelihood ratio index than other models, it was judged that Model 10 is the "best" model and was used in the following section to examine the effect of individual variables.

The "best" model specification was used to test whether the results would change if all situations were included, instead of just the reduced data set. The results showed that all the estimated coefficients had the same signs as those for the model developed using the reduced data set (exclude non-choice situations). The values of the estimated coefficients in the two models were almost the same. The likelihood ratio indices show that, the model developed using all the data set, fit the data better than the model using the reduced set.

Criteria	exclude non-choice situations (Model 10 in Table 6.13)	All data
LL(0)	-4425.05	-5997.11
LL(β)	-1372.25	-1432.31
LL(c)	-4191.56	-5811.86
$(\rho^2)(0)$	0.690	0.762
$(\rho^2)(0)$(AIC)	0.685	0.758
(ρ^2)(c)(AIC)	0.673	0.754
% correct	87.12	90.16

Model 11 in Table 6.13 has the same model specification as Model 10 except, it includes Tgap instead of space gap and speed. This model was used to calculate the effect of individual factors in terms of time gap as described in the following section.

Comparison of the "best" model to the time gap only model:

Model 11 in Table 6.13 was compared with the model that included only time gap. The following represent the results of this comparison.

Criteria	Final best model (that include Tgap)	Time-gap only model
LL(0)	-4425.05	-4425.05
LL(β)	-1355.8749	-1596.09
$\rho^2(0)$	.6936	0.639
$\rho^2(0)$(Aic)	.689	0.639
%correct	87.27	84.9

Testing the null hypothesis, that the restrictions to the final model are true (restrictions are that all parameter coefficients except for time gap and alternative specific constants are equal to zero) yield the following results:

Unrestricted model = final model (Model 11 in Table 6.13)
Restricted model = Time gap only model

$$X^2_{calculated} = -2\ [\ L(\beta_R) - L(\beta_U)]$$
$$= -2\ [-\ 1596.09 + 1355.87] = 480.44$$

X^2 value for 20 degree of freedom and 95% confidence level = 31.4
Therefore, the null hypothesis, that the restrictions to the final model are true, is rejected.

The modified likelihood ratio index $\rho^2(0)$(Aic) for the final model is higher than that for time-gap only model, and the difference between the indices (0.689 - 0.639 = 0.05) is greater than 0.01. Therefore, the final model is considered to be superior to the time gap only model (Horowitz, 1982).

6.10 INDIVIDUAL VARIABLES AND THEIR IMPORTANCE

This section describes the impact of individual variables on the probability of accepting the immediate gap. The relative importance of these variables as factors in the decision-making process is discussed and their statistical significance indicated. The impact is then illustrated by expressing the influence of the factor in terms of an equivalent change in the space gap or time gap, that would yield the same change in the gap acceptance probability, provided that all other variables remained unchanged.

The overall "best" model, on the basis of the statistical indicators and informal tests, was Model 10 in Table 6.13 (section 6.9) and therefore was used, examining the effect of individual variables in terms of the equivalent effect of space gap. The time gap model (Model 11 in Table 6.13) was also used to examine the effect of variables in terms of time gap. The relative values of parameters to both space gap and time gap are given in Tables 6.14, and 6.15. The influence of these variables on gap acceptance is shown in Figures 6.5 to 6.10.

Table 6.14 Relative Value of Parameters to Value of Space Gap (in metres)

(a)

Male vs. Female	Age-Y vs. Age-O	Age-M vs. Age-O	Pass vs. no pass	Acc-L vs. Acc-H	Acc-A vs. Acc-H	TypeP vs. TypeBI	TypeT/B vs. TypeBI	TypeM vs. TypeBI
+8.41	+3.05	-2.09	-5.15	-1.48	-1.30	-14.05	-14.41	-27.92

(b)

Qdelay	Fdelay 0-1.5	Fdelay 1.5-20	Fdelay 20-30	Fdelay >30	Speed	Flow	VehBeh	# of lanes
+0.34	-9.68	-0.52	-2.72	+1.57	-0.92	+1.48	+3.27	-10.18

Table 6. 15 Relative Value of Parameters to Value of Time Gap (in seconds)

(a)

Male vs. Female	Age-Y vs. Age-O	Age-M vs. Age-O	Pass vs. no pass	Acc-L vs. Acc-H	Acc-A vs. Acc-H	TypeP vs. TypeBI	TypeT/B vs. TypeBI	TypeM vs. TypeBI
+.46	+.17	-.10	-.30	-.10	-.07	+.19	+.08	-.36

(b)

Qdelay	Fdelay 0-1.5	Fdelay 1.5-20	Fdelay 20-30	Fdelay >30	Flow	VehBeh	# of lanes
+.02	-.56	-.03	-.15	+.08	+.09	+.19	-.2

Discussion of the effect of these variables is presented below:

Gender

All other things being equal, the probability of a given gap being accepted is higher for males than it is for females. The coefficient estimate for Gender is statistically highly significant. The coefficient estimate indicates that, on average, a female driver must have a gap that is 8.41 m (0.46 s) longer in order to have the same probability of acceptance as a male driver as shown in Figure 6.5.

Age

The coefficient estimate for this factor is statistically not significant and its influence is very small. The probability of accepting a gap increases in the following order: middle-age drivers, old, young. Compared to an "old" driver, a "young" driver would accept a gap that is 3.05m (0.17 s) shorter, and a "middle-age" driver would accept a gap 2.09 m (0.10 s) longer as presented in Figure 6.6.

Presence of Passengers

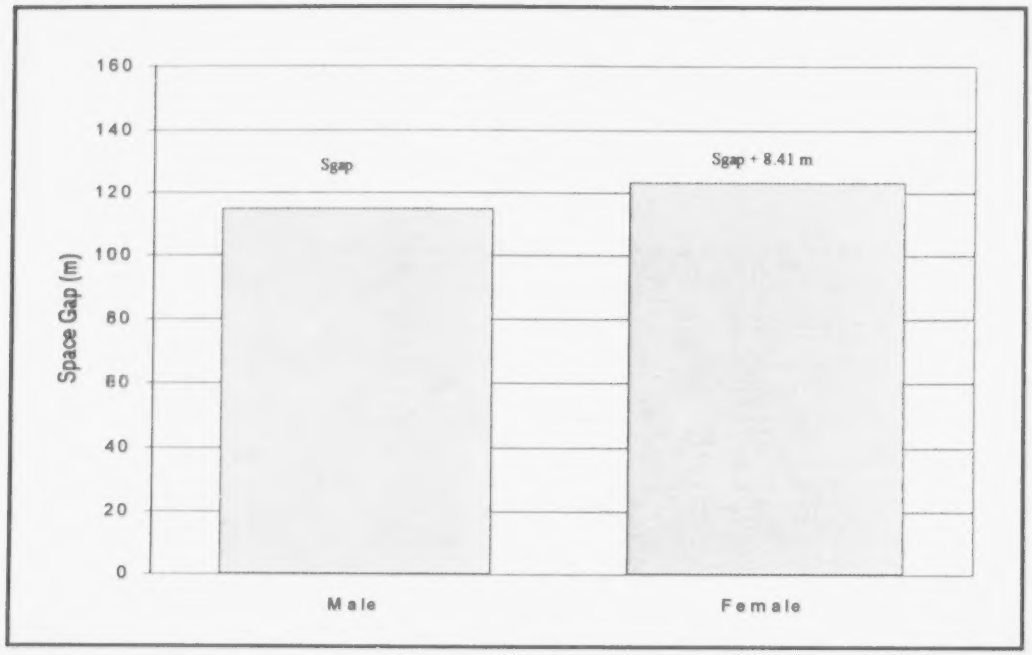
The coefficient estimate for this factor is statistically highly significant. The probability of accepting a gap decreases if there are passengers in the vehicle turning left. Compared to vehicles with no passengers, drivers with passengers would accept a gap 5.15 m (0.30 s) longer on the average as illustrated in Figure 6.7.

Acceleration Capability of the Turning Vehicle

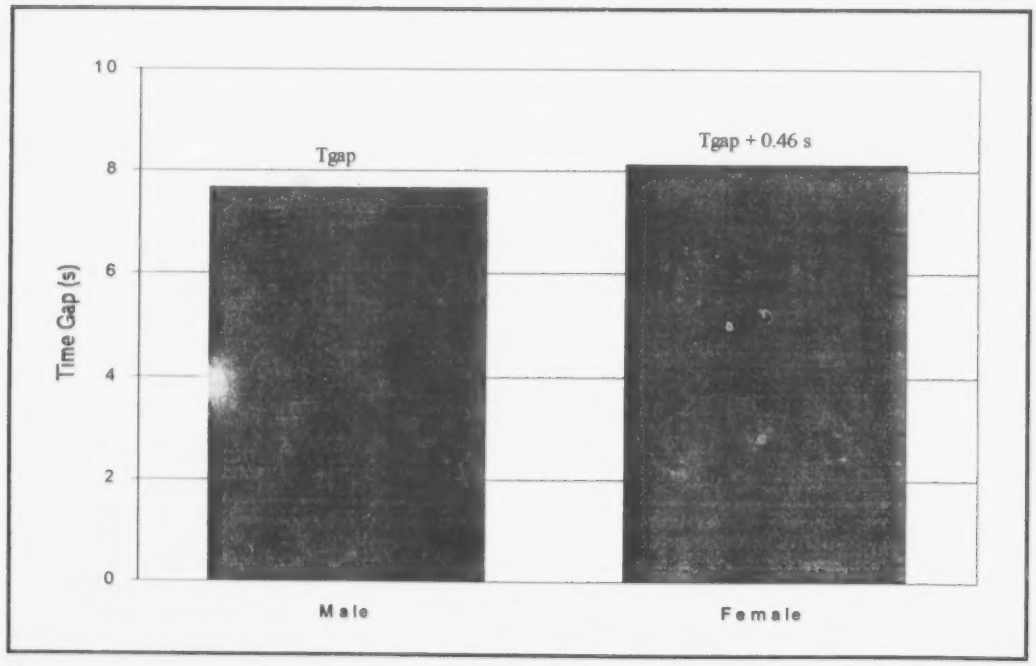
This factor was classified by the model and age of the vehicle. Its coefficient estimate was statistically insignificant. Nevertheless, the probability of accepting a gap increases in a logical order: low, average, high acceleration capability. For instance, driving a low and an average acceleration vehicle respectively, compared to a vehicle with high acceleration potential, increases the average gap accepted by 1.48 m (0.10 s), and 1.30 m (0.07 s) as shown in Figure 6.8.

Queue Delay

The coefficient estimate for this factor is statistically highly significant. The probability of accepting a gap increases as queue delay increases. Drivers are willing to accept gaps shorter by 3.4 m (0.2 s) for every 10 seconds they were delayed in the queue.

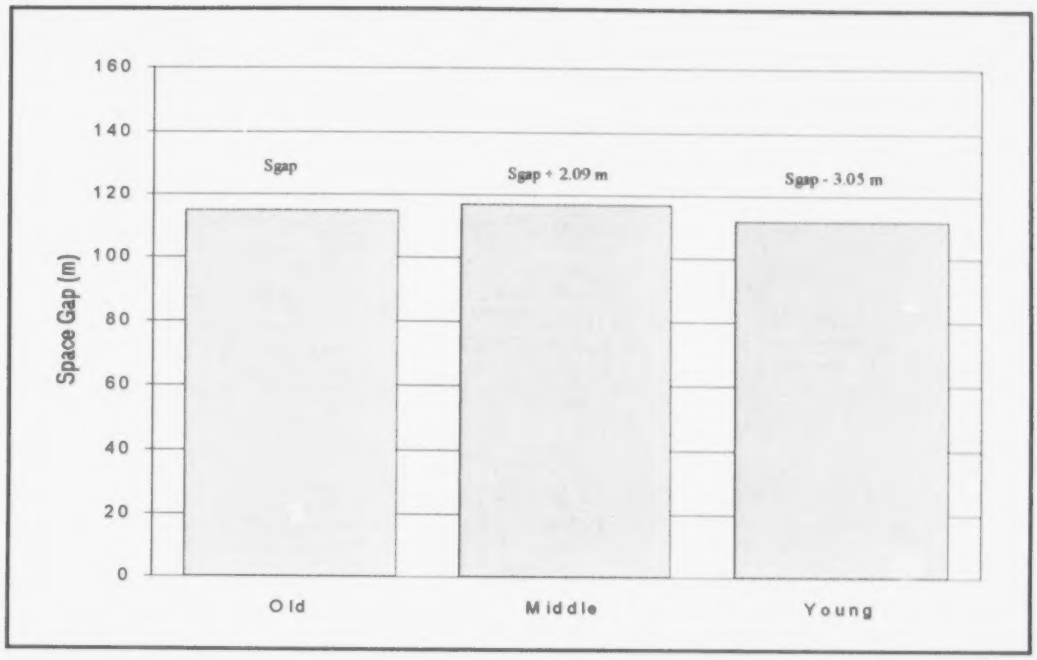


a.



b.

Figure 6.5 Influence of Driver Gender on Gap Acceptance



a.

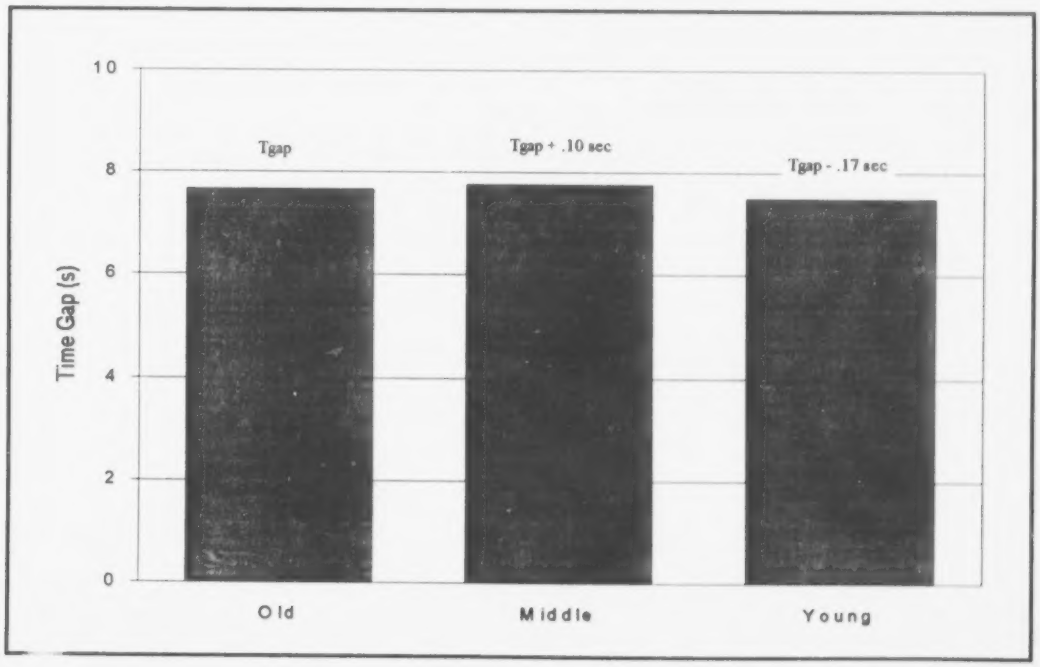


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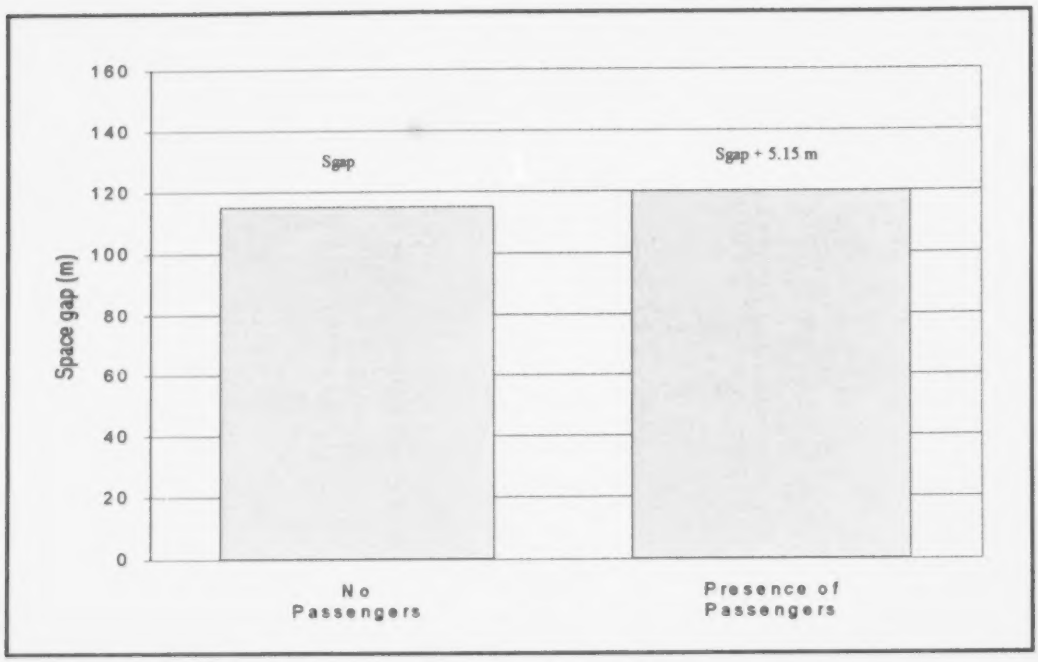
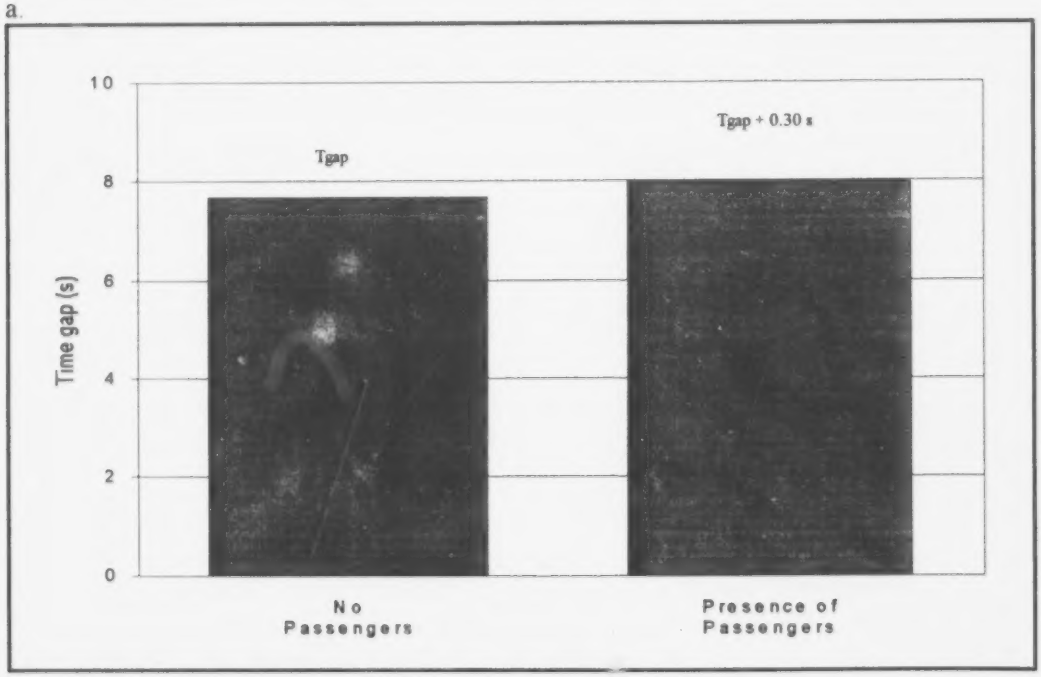
Figure 6.6 Influence of Driver Age on Gap Acceptance

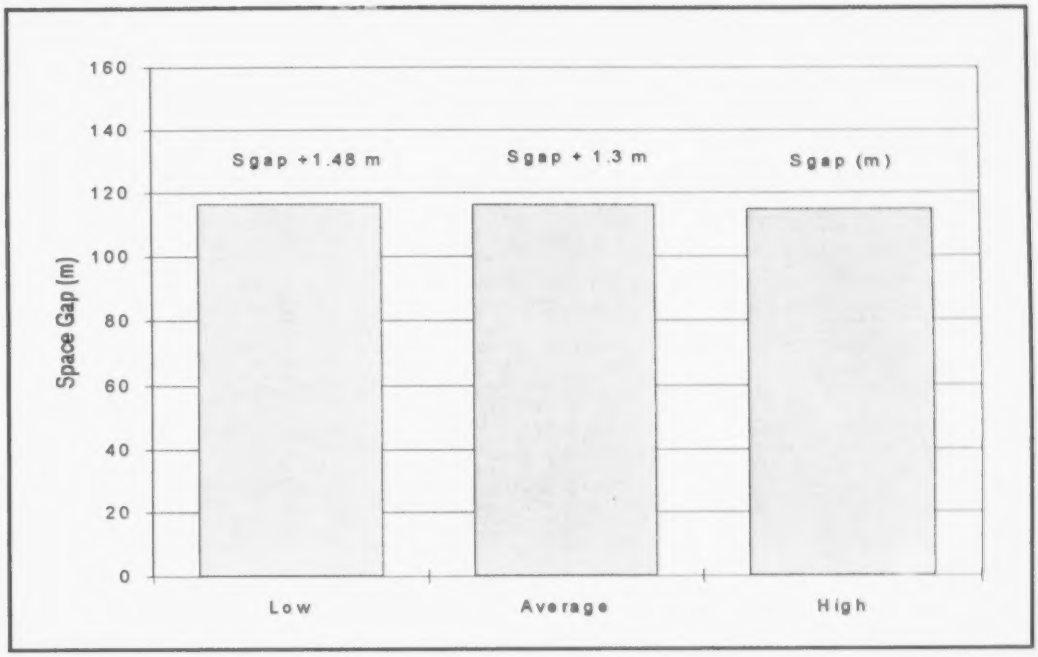


a.

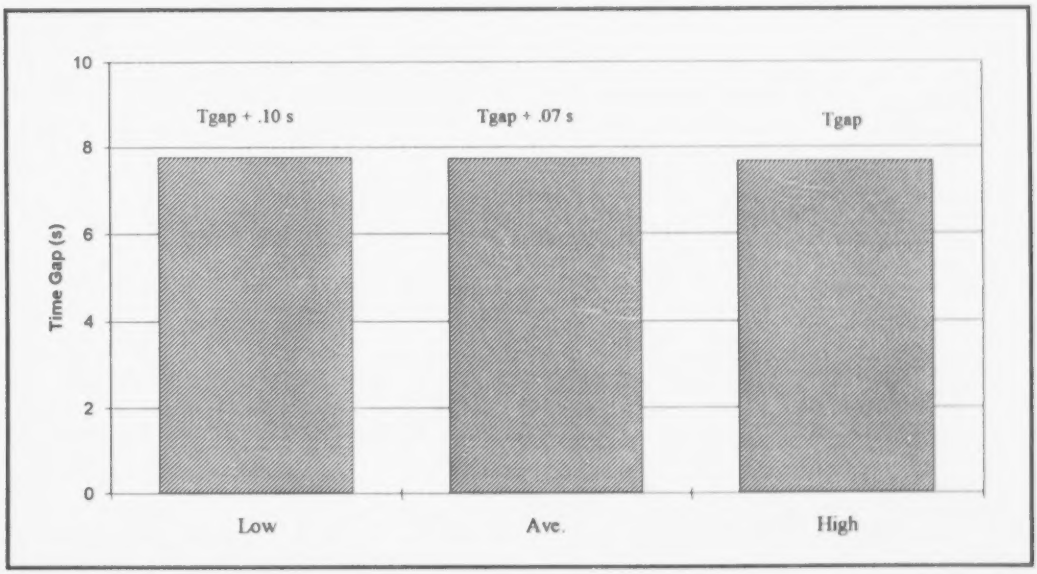


b.

Figure 6.7 Influence of Presence of Passengers on the Gap Acceptance



a.



b.

Figure 6.8 Influence of Acceleration Capability of the Gap Acceptance

Front Delay

The coefficient estimate for this factor is statistically highly significant. Figure 6.9 shows the impacts of the front delay on the size of the accepted gap. In this figure, drivers who did not stop at the intersection are assumed to accept a 7.66 s gap which is the average accepted size for those drivers. When the drivers stop, they wait for longer gaps. Having to stop at the head of the queue for 1.0 s is equivalent to an increase in the average gap accepted of 0.56 s. This means that they would accept an 8.5 s gap at a 1.5 s front delay. Drivers who were delayed in the range of 1.5 s to 20 s would accept a gap which is 0.3 s longer for each 10 s of delay. In this case they would accept a 9.1 s gap at a 20 s front delay. If they had to wait an additional 10 s, they would accept gaps 1.5 s longer. This means that they would accept a 10.6 s gap at 30 s front delay. This is an unexpected finding that would deserves further study. Those delayed beyond 30 s were prepared to use gaps that were shorter by 0.8 s for every 10 s of this additional front delay. They would accept 9.4 s gap at 45 s front delay. In this study, the front delay data range did not extend much beyond 45 s because in the Edmonton region, intersections with longer delays occur have tended to be signalized.

Time Gap

As expected, the coefficient estimate for this factor is statistically highly significant. The probability of accepting a gap increases as the time gap size increases. The time gap seemed to be an adequate approximation for space gap (distance), speed, and type of opposing vehicle

Space Gap

Again, as expected, the coefficient estimate for this factor is statistically highly significant. Because the space gap is highly correlated to the time gap, they were not used together. The probability also increases as the space gap size increases.

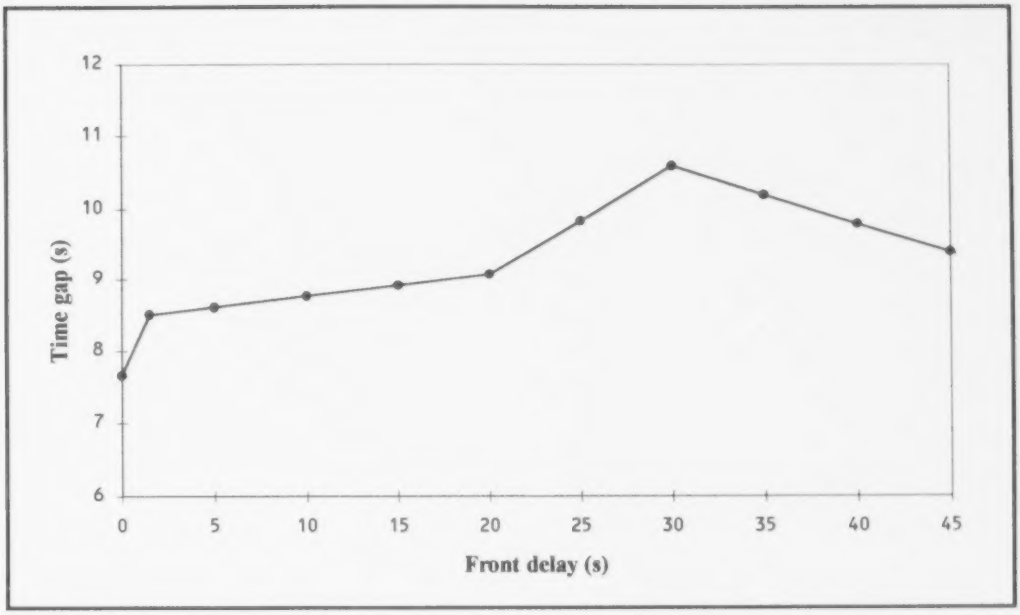


Figure 6.9 Effect of Front Delay on the Size of the Accepted Gap

Speed of the Opposing Vehicle

In the model that includes space gap and speed, it was found that the coefficient estimate for this factor is statistically highly significant. The probability of accepting a gap decreases as the speed increases. For each increase of 10 km/h in the opposing vehicle's speed, a left-turning driver will wait for a gap that is longer by 9.2 m. In the model that includes time gap, it was found that as speed increases, the probability of accepting a gap increases. This can be explained as for the same time gap, as speed increases distance gap increases which make the gap acceptable. This explanation is suspected since the speed and distance gap were found to be independent or poorly correlated.

Space Gap and Speed Together

Both the space gap and speed model, and the time gap model fit the data almost equally, but the space gap and speed combination gives a slightly better model fit than using the time gap alone. This slight difference does not confirm whether drivers perceive the distance gap, or the time gap.

Type of Opposing Vehicle

The coefficient estimate for this factor is statistically significant in the models using space gap and speed, but not in the models that used the time gap. Results of the model that included space gap indicated that the probability of accepting a gap increases in the following order: motorcycle, truck or bus, passenger car, bicycle as shown in Figure 6.10a. This means that if the opposing vehicle is a motorcycle, the left-turning drivers are most reluctant to accept the associated gap.

Number of Gaps Rejected

The results were consistent with the effect of front delay.

Microscopic Flow of Opposing Traffic

The coefficient estimate for this factor is statistically highly significant. The probability of accepting a gap increases as the flow increases. Drivers will accept gaps shorter by 14.8 m (0.9 s) for every 10 additional vehicles per minute in the opposing flow. It appears that the drivers judge their future chances on the basis of the intensity of the opposing flow.

Presence of Vehicles Behind the Left-Turning Vehicle

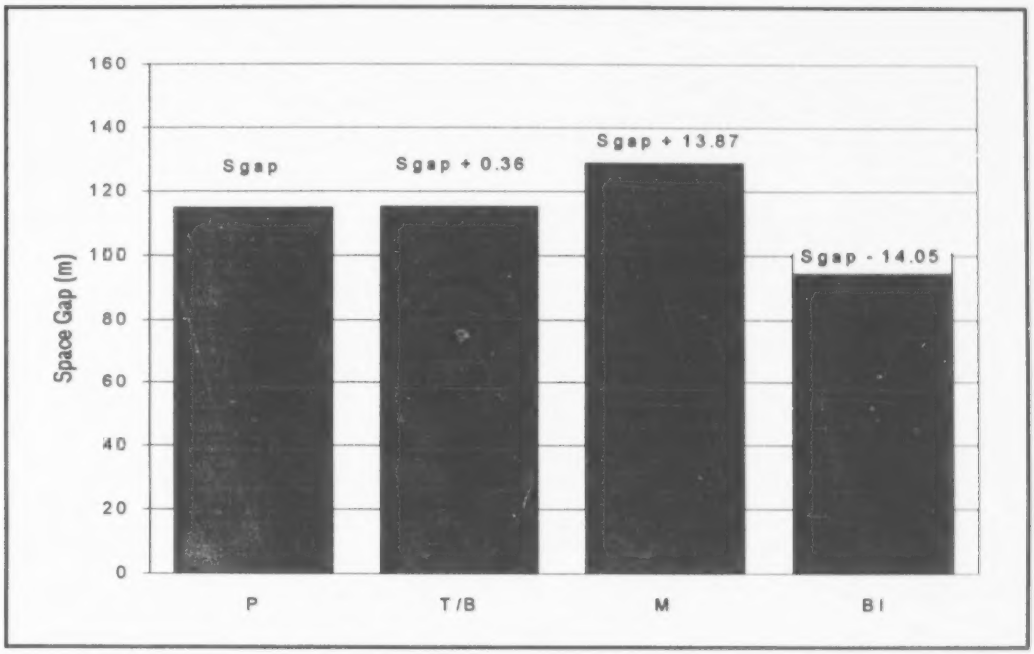
The coefficient estimate for this factor is statistically significant. The probability of accepting a gap increases if there are vehicles in the queue behind the turning vehicle, and the size of the accepted gap decreases by 3.27 m (0.19 s). Practicing traffic engineers usually describe this effect under "traffic pressure". It has to be mentioned that the number of vehicles behind the turning vehicle was not considered in this research.

Number of Lanes to Cross

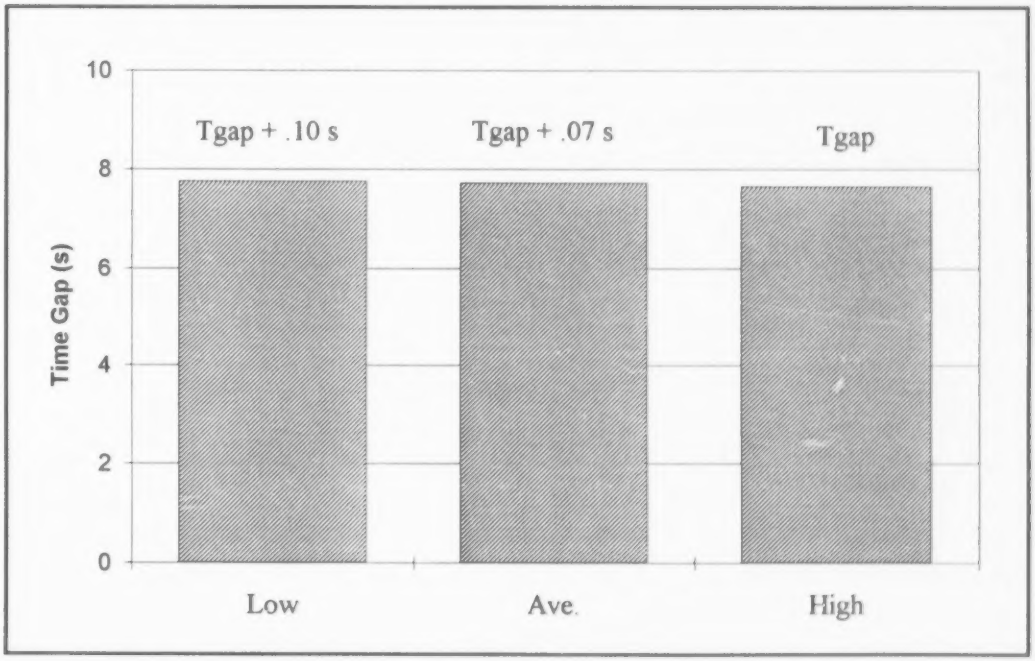
The coefficient estimate for this factor is statistically highly significant. The probability of accepting a gap decreases if the number of lanes increases. Drivers wait for gaps longer by 10.18 m (0.2 s) for every additional lane to cross.

Location Specific Constant

This variable was included to account for some of the differences in individual locations not represented by the number of lanes or other variables. The coefficient estimate for this factor is statistically highly significant.



a.



b.

Figure 6.10 Influence of Type of Opposing Vehicle on the Gap Acceptance

6.10 SUMMARY

This Chapter presented the results of different model estimations. The utility function of the best Model is found to be as follows:

$$
\begin{aligned}
V = &- 0.397 + 0.707\ \textbf{Gender} + 0.257\ \text{Young} - 0.176\ \text{Middle} - 0.433\ \textbf{Pass} - \\
&\quad (0.568) \quad (6.60) \quad (1.04) \quad (0.76) \quad (3.91) \\
&- 0.124\ \text{low} - 0.110\ \text{Ave} + 0.029\ \textbf{Qdelay} - 0.814\ \textbf{Fdelay(0-1.5)} - \\
&\quad (0.56) \quad (0.52) \quad (4.29) \quad (8.56) \\
&- 0.044\ \textbf{Fdelay(1.5-20)} - 0.228\ \textbf{Fdelay(20-30)} + 0.132\ \textbf{Fdelay(>30)} - 0.077\ \textbf{Speed} + \\
&\quad (2.69) \quad (3.69) \quad (3.53) \quad (14.98) \\
&+ 0.084\ \textbf{Sgap} - 1.182\ \textbf{TypeP} - 1.212\ \textbf{TypeT/B} - 2.349\ \textbf{TypeM} + 0.124\ \textbf{Flow} + \\
&\quad (34.65) \quad (1.93) \quad (1.85) \quad (2.34) \quad (13.91) \\
&+ 0.275\ \textbf{VehBeh} - 0.856\ \textbf{\# lanes}\ \text{-1.330 (99St)} - 0.331\ \text{WE} \\
&\quad (2.17) \quad (8.84) \quad (7.53) \quad (2.34)
\end{aligned}
$$

Statistically significant variables are set in bold print and the numbers in brackets are t-statistics of the estimated parameters.

-The goodness of fit $\rho^2(0) = 0.695$

-The goodness of fit $\rho^2(0)(\text{Aic}) = 0.690$

-Alternative 1 (accept) was predicted successfully 83% of the times, while alternative 2 was predicted successfully 90% of the times. The average prediction success was 87%.

A Summary of the main findings from this Chapter is presented in Chapter 7.

CHAPTER 7

FINDINGS AND CONCLUSIONS

The objective of this research was to enhance the understanding of driver gap acceptance behaviour. The goal was not to develop a general applicable model to be used in capacity analysis or design, but to determine which factors play a role in the driver's gap acceptance behaviour. These factors were classified as driver's characteristics, and gap attributes. Although some guidelines can be found in the past research literature regarding the effect of the individual factors, little is known about their combined effect. This research project investigated the overall behavior as influenced by many of these factors together. The gap acceptance problem was considered as a series of consecutive choice situations where drivers have to decide whether to accept or reject an available gap between opposing vehicles in the major stream. Over 40 utility functions, including different combinations of factors that were thought to affect a driver's gap acceptance decision, were estimated and examined. The factors were represented in these functions as variables. Data used for model estimation were collected from five intersections and included observations of 3,434 left turning drivers accepting or rejecting gaps between 13,067 through vehicles. A total of 6,384 choice situations were used for model estimations.

Section 7.1 presents the main findings of this research. General conclusions, evaluation of data collection and model estimation techniques that were used in this research, and the practical application of the research are presented in Section 7.2. Section 7.3 provides recommendations for future research.

7.1 MAIN FINDINGS

7.1.1 Findings From Data Analysis

The following findings are based on the statistical analysis of the collected data. Each variable was analyzed alone without considering the effect of the other factors. The results of data analysis indicated the following:

a. Driver gender: Male drivers on average represented approximately 63% of total drivers in the study sample, but they were involved in only 60 % of the total observed choice situations. This means that on average a female driver rejected a larger number of gaps than a male driver before accepting a gap.

b. Driver age: Young drivers represented on average 24 % of total drivers in the study sample, but they were involved only in 22.7 % of the total choice situations. The difference is very small to confirm that young drivers rejected less gaps than other drivers before accepting a gap.

c. Presence of passengers in the turning vehicle: On average, left turning vehicles that had passengers represented 30 % of the total observed turning vehicles. These vehicles were involved in 31 % of the observed choice situations. The difference is too small to indicated that drivers with passengers rejected more gaps than drivers without passengers.

d. Acceleration capability of turning vehicles: Although high acceleration capability vehicles represented 6.3 % of total observed vehicles, they were involved only in 5% of total choice situations. The difference is also too small to indicate that drivers of the high acceleration capability vehicles rejected less gaps than drivers of average and low acceleration capability vehicles.

e. Size of the accepted and rejected gaps: It was found that no drivers rejected a gap greater than 13 seconds or accepted a gap less than 1 second.

f. Distributions of the gaps accepted: Distribution of the accepted gaps for drivers who did not stop at the intersection was similar to the distribution for drivers who stopped. A small percentage (1.1%) of drivers who did not stop accepted gaps shorter than 3 seconds.

g. Distribution of the gaps accepted for drivers with different ranges of front delay: The gap acceptance distribution for drivers with a front delay between 0 to 15 seconds was almost identical to that for drivers who experienced 15 to 30 seconds front delay (with the exception of those who did not stop). The highest probability for those two groups was for gaps around 6.0 to 7.0 seconds compared to 5.0 seconds for drivers with front delay >30 seconds.

h. Drivers Who Accepted Gaps Shorter Than Gaps Previously Rejected : 58 drivers accepted gaps shorter than one or more gaps they previously rejected. 5.2% of those drivers incurred front delay greater than 30 seconds compared to 1.25% for the total observed drivers. 57% of drivers, who accepted gaps shorter than those previously rejected, accepted gaps equal to or less than 5 seconds compared to only 8% of all drivers who waited for a longer gap.

i. Number of lanes (or the width) to be crossed: From comparing data at different locations, it was found that the wider the road, the higher the minimum accepted time gap at this location.

7.1.2 Findings From Model Estimations

The "best" utility function has been used to determine the probability of accepting a gap for a given set of driver characteristics and gap attributes. The effect of different variables on the probability of accepting a gap was interpreted using the signs of the coefficient estimates, t-statistic values as well as relative value of variables coefficient estimates. The relative importance of variables was calculated by keeping the probability constant and relating all variables coefficients to the gap size coefficient. The gap size, presented as time gap and space gap, was chosen because it is the most used term in practice and is easy to interpret. Following are several important findings that were derived from the model estimation stage. The findings agree with the results from data analysis stage.

A. Significant Factors

The coefficient estimates for the following variables were found to be statistically significant at 90% level of confidence: gender, presence of passenger in the turning vehicle, delay, gap size, speed, type of opposing vehicle, opposing flow rate, presence of vehicle behind, and number of lanes. The effect of these variables on the gap acceptance can be summarized as follows:

a. Gender: the probability of a given gap being accepted is higher for males than it is for females. On average, a female driver required a gap that is 8.41 m (0.46 s) longer

in order to have the same probability of acceptance as a male driver. This finding confirmed the result of previous research as reported by Wennell and Cooper (1981) which showed that the difference in the median accepted gap between male and female is almost half a second.

b. Passengers in the turning vehicle: The probability of accepting a gap decreases if there are passengers in the vehicle turning left. Number and type of passengers in the turning vehicle were not considered in the research. Compared to vehicles with no passengers, drivers with passengers would accept a gap 5.15 m (0.30 s) longer on the average. This finding contradict results of previous research by Wennell and Cooper (1981) who found that there is no consistency on the effect of the presence of passengers on the size of the median accepted gap.

c. Queue delay: The probability of accepting a gap increases as queue delay increases. This finding is supported by result of previous research by Kyte et al. (1991). Drivers are prepared to accept gaps shorter by 3.4 m (0.2 s) for every 10 sec they were delayed in the queue.

d. Front delay: Drivers who arrived at the head of the queue, with the vehicle still in motion, tend to accept very short gaps. After that, once they are stopped, they wait for longer gaps, perhaps selecting and assessing relevant stimuli and "learning" what is involved. After about 30 s of waiting, they consider shorter gaps. Having to stop at the head of the queue was equivalent to an increase in the average gap accepted by 9.68 m (0.56 s). Drivers who were delayed in the range of 1.5 to 20 s accepted a gap longer by 5.2 m (0.3 s) for each 10 s of delay. This was an unexpected finding that deserves further study. Drivers who were delayed beyond 30 s are prepared to accept gaps shorter by 15.7 m (0.8 s) for every 10 s of this additional front delay. This was an important finding that is supported by empirical observations in many regions. After a delay of about 40 s, drivers have a tendency to accept gaps of a previously rejected size.

The result is similar to finding from previous research (for instance; Ashworth and Bottom, 1977, Kittelson and Vandehey, 1991, and Kyte et al. 1991) that indicated that the longer the waiting time at the head of the queue, the greater the probability of gaps being accepted. The result regarding front delay less than 30 seconds (probability of

accepting a gap decreases as front delay increases) is not supported by any previous research and requires further investigations.

e. Gap size: The probability of accepting a gap increases as the gap size increases (time gap or space gap). This result is consistent with previous studies.

f. Speed of the opposing vehicle: The effect of the speed varied between two different model specifications. The result of the first specification that included time gap, showed that the probability of accepting a gap increases as the speed of the opposing vehicle increases. This finding, even if it does not appear logical, is supported by previous research by Ashworth and Bottom (1977). Their explanation of the result was that, for the same gap size in time, the higher the speed the higher the distance gap that makes it acceptable by drivers. This may not be necessarily true since the correlation coefficient between speed and space gap (0.26), indicates that these two variables are independent or poorly correlated. This point deserves further research.

The result of the second model specification, that included space gap, indicated that the probability of accepting a gap decreases as the speed increases. The drivers of the left-turning vehicles waited for gaps longer by 9.2 m, for a 10 km/h increase in the speed of the opposing vehicles.

g. Flow rate of the opposing traffic: the probability of accepting a gap increases as the flow increases. Drivers will accept gaps shorter by 14.8 m (0.9 s) for every 10 additional vehicles per minute in the opposing flow. The reduction in the size of the accepted gap is consistent but the magnitude found in this research seems very conservative compared to the finding of previous research [for instance; approximately 1 second for 1 veh/min increase (Polus, 1983) and between 4.3 to 6.4 seconds for 10 veh/min increase (Kyte et al., 1991)].

h. Presence of vehicles behind the turning vehicles: the probability of accepting a gap increases if there are vehicles in the queue behind the turning vehicle. The size of the accepted gap decreases by 3.27 m (0.19 s) if there are vehicles behind which shows the effect of traffic pressure on driver decision.

i. Numbers of rejected gaps: The effect of the number of rejected gaps was similar to that for front delay. For the number of previously rejected gaps up to 14, as the

number of rejected gaps increases, the probability of accepting a gap decreases, while the probability of accepting a gap increases if the number of rejected gaps was >14. For the number of rejected gaps >14 though, the coefficient estimate was found to be statistically insignificant. No further detailed study was conducted regarding number of rejected gaps.

j. Number of lanes to cross: The probability of accepting a gap decreases if the number of lanes increases. Drivers wait for gaps longer by 10.18 m (0.2 s) for each additional lane to be crossed.

B. Less Significant Factors

The coefficient estimates for several variables were found to be statistically insignificant, indicating that the corresponding variables do not have a strong influence on gap acceptance behaviour. These variables and their effect can be summarized as follows:

a. Age: The probability of accepting a gap increases in the following order: middle-age drivers, old, young. Compared to an "old" driver, a "young" driver would accept a gap that is 3.05 m (0.17 s) shorter, and a "middle-age" driver would accept a gap 2.09 m (0.10 s) longer. It has to be kept in mind that the definition of the middle age as neither old or young was vague.

b. Acceleration capability of the turning vehicle: the probability of accepting a gap increases in a logical order: low, average, high acceleration capability. For instance, driving a low acceleration vehicle, compared to a vehicle with high acceleration potential, increases the average gap accepted by 1.48 m (0.10 s), and an average acceleration vehicle by 1.30m (0.07 s).

c. Type of the opposing vehicle: The coefficient estimate for this factor was found to be statistically significant in the models using space gap and speed, but not in the models that used the time gap. The probability of accepting a gap increases in the following order: motorcycle, truck or bus, passenger car, bicycle. This finding is somewhat different from the finding of Hancock et al. (1991) who found that drivers rejected more gaps in front of large vehicles than in front of other types.

7.2 CONCLUSIONS

7.2.1 General Conclusions

1- Overall, the research developed a statistically reliable set of models that helped to understand the effect of different factors on a driver's decision to accept or reject a given gap.

2- Both space gap and speed model and time gap model almost fit the data equally, although the space gap and speed model is slightly better. This finding could not indicate whether drivers perceive the distance and the speed of the opposing vehicle, or the time gap.

3- The final developed model that included time gap is superior to the time only model.

4- The time gap is a sufficient surrogate for space gap (distance), speed, and type of opposing vehicle.

5- In this study, the number of observations used for parameter estimates was over the sample size requirement (at least 1,000 observations) as mentioned in the previous study by Koppelman and Chu (1983). In model estimation, using a subset of the data of less than 1000 observations (e.g. examining different experience of delay), the coefficient estimates of the parameters became statistically not different from zero.

6- It has to be kept in mind that this research only focused on left turns from a main street into a minor street at T-intersections without traffic signals. Most situations are more complex than the studied one, therefore the results of this study may not be applicable for different situations. For example, at the same T-intersection, the left turning movement from a minor street into a major street is quite different than the studied movement, in that it has lower priority at the intersection and drivers face conflicting traffic from both directions. The situation will also be different if pedestrians are involved, where drivers must find a suitable gap among pedestrians and vehicles.

7.2.2 Evaluation of Data Collection Technique

1- Using video taping and the walkie-talkies for data collection proved to be an appropriate method for collecting detailed and simultaneous data. The video taping also provided a permanent record of traffic movements, allowing each tape to be viewed many times.

2- Observing traffic from video tapes required a large TV screen (greater than 28") for a clear view of vehicle movements.

3- Entering the data using the traffic data input program (TDIP 1991) was not difficult, but needed the full concentration of the person at the keyboard and no external interruption to prevent errors. It is a user friendly program, and correctness of data entry could be checked from the information displayed on the computer screen. It was also useful that the program could transfer entered data files into spreadsheet files to permit further analysis.

4- Data entry errors caused the only problems encountered while using the input program. Although the program could be stopped and a new data file started before the error, the extra data had to be removed from the previous data file manually.

7.2.3 Evaluation of Research Method

1. A discrete choice model proved to be a valid approach for studying a micro-situation in traffic.

2. The multinomial logit model allowed incorporation and analysis of a large number of variables. It proved to be a useful tool in the rational sequential identification and investigation of promising model structures.

3. The logit model and the associated computer program (NTELOGIT 1992) were relatively easy to use. One of the main advantages of the program is that it provides many statistical parameters for testing individual variables, as well as the overall model fit.

4- The number of iterations required for convergence of the logit program made analysis demanding with regard to program running time (over 30 minutes on 386DX25

IBM compatible computer without mathcoprocessor for each run). The running time decreased dramatically when using a 486 DX2/50 computer (approximately 6 minutes running time for each run).

7.2.4 Practical Application

Since practical application was not one of the research objectives, no attempt was made to make the model transferable. The developed model was not validated at other intersections or regions.

Some direct use of the developed utility function in simulation is feasible. Some simplification would be necessary, keeping in mind that most intersections are not of the T shape studied in this research. The results of this research may not apply to different movements and different intersection shapes, especially where there are more than one priority movements involved.

7.3 FUTURE RESEARCH

This research has improved the understanding of driver gap acceptance behaviour using the most essential elements of the decision. However, there are a number of specific aspects that should be investigated in the future. These can be identified in two categories: those directly related to the findings of this research project, and those related to the subject of the research.

1. Aspects directly related to the findings of this research project

a. Effect of the speed of opposing vehicle on driver gap acceptance
b. Analysis of the impact of variables within broader ranges (e.g., heavier opposing traffic and longer waiting time at the intersection).
c. Further investigation of front delay, i.e. the change in driver behaviour that takes place while driver waits at the head of a queue.
d. Effect of the length of the queue behind the turning vehicle
e. Effect of gender and age of passengers in the turning vehicles
f. Effect of other driver characteristics

2. Aspects related to the subject of the research

a. The change in behaviour between day and night time,
b. The change in behaviour between summer and winter conditions,
c. The effect of weather, and pavement condition (wet versus dry).
d. The effect of type of turning vehicle
e. The effect of pedestrians
f. The development of a simplified practical model that would incorporate major factors influencing gap acceptance.
g. Focusing on driver rather than gap as a different paradigm for studying the gap acceptance problem possibly using a different investigation method.

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APPENDIX A

Choice Based Models

Probit Model

Sheffi and Mahmassani (1981) studied driver behaviour when faced with an amber indication using the probit model. This situation was viewed as a binary choice process where the decision is either to stop or to proceed through the intersection. Assuming T is the time to reach the stop line as perceived by a driver: $T=t+\xi$ where t is the measured time to get to the stop line and ξ is random variable reflect the differences in drivers' perception.

The hypothesis is if T is less than critical value T_{cr}, then driver would choose to proceed through the intersection. Every driver is assumed to have his own critical value as follows: $T_{cr} = t_{cr}+\varepsilon$ where t_{cr} is the mean critical time and ε is random variable. The probability that a random driver would choose to stop is given by the probit equation:

$$P_{stop} = Pr\{ T_{cr} < T \}$$

$$= \Phi \frac{t - t_{cr}}{\sigma} \qquad \text{(model 1)}$$

Where $\Phi(.)$ is the standard cumulative normal function,

$\sigma = \sqrt{\sigma_\xi^2 + \sigma_\varepsilon^2 + 2\sigma_{\xi,\varepsilon}}$,

$\sigma_{\xi,\varepsilon}$ is the covariance of ξ and ε

Model's parameters (t_{cr},σ) have been estimated by maximizing the following log likelihood function.

$$L(t_{cr},\sigma) = \sum_{i=1}^{I} \log\Phi\left(\frac{t_i - t_{cr}}{\sigma} * C_i\right)$$

Where I is the sample size,

C_i is the choice made by driver i (C_i=1 if driver stopped,

C_i= -1 if driver proceeded)

t_i is the measured time for driver i to get to the stop line.

Another likelihood function was tested (model 2) similar to the previously mentioned function except using critical time as a function of speed:

$T_{cr} = a + bV + \varepsilon$

where V is the speed of the vehicle at the amber indication,

a, b, σ are parameters to be estimated.

The following results regarding parameter estimates and T-statistic showed that all parameters were statistically different from zero with 98% level of confidence. The results also proved that the critical time is an increasing linear function of speed.

Parameter	Model 1	Model 2
t_{cr}	5.09	
(T-statistic)	(65.58)	
a		3.90
(T-statistic)		(6.77)
b		0.028
(T-statistic)		(2.096)
σ^2	2.41	2.40
(T-statistic)	(9.11)	(9.052)
Log-Likelihood at zero L(0)	-693.15	-693.15
Log-Likelihood at convergence L(β)	-410.73	-408.54
Likelihood ratio index	0.41	0.41

Fuzzy Set Theory

Fuzzy set theory has been used to analyze individual driver's decision between "stop" and "clear" during signal change interval (Kikuchi and Riegner 1991). Information available to a driver concerning location, approach speed, time remaining in the signal change interval and other parameters is fuzzy (known to him only approximately based on experience, familiarity with the intersection and signal and feeling). Driver must make the decision based on this fuzzy information. Fuzzy sets of "safe stopping", "safe clearing" and driver location were defined along intersection approach. Driver's certainty of completing "safe stopping" and "safe clearing" was identified by taking the intersections of the fuzzy set of driver location with fuzzy sets of "safe stopping" and "safe clearing". Possibility and necessity measures of "safe stopping" and "safe clearing" were defined and were believed to represent the decision criteria of aggressive and conservative drivers, respectively.

METHODS OF COLLECTING GAP ACCEPTANCE DATA

1- Time-Lapse Photography (Time-Motion Pictures)

Solberg and Oppenlander (1966) used time-motion pictures for collecting necessary data. A 16-mm camera with a wide-angle lens was used. A spring motor drove the camera at the rate of 8 frames per second, so the time intervals were measured to the nearest 0.125 sec. The camera was mounted at some point near the side-street approach, about 10 m (30ft) from the main street and it was relatively inconspicuous to the passing traffic. Data were collected on weekdays in the morning and afternoon off-peak periods. The camera was started whenever a side-street vehicle approached the intersection and was stopped after the driver had accepted a time gap. The maximum considered time gap was 15 seconds. The developed film was viewed by a time-motion study projector which had a frame counter. The time-lag was recorded as the difference in frame numbers, between the arrival of minor stream vehicle and crossing its path by major stream vehicle, divided by 8 frames per second. A time-gap was recorded as the difference in frame numbers between two successive main-street vehicles, divided by 8 frames per second.

Ashworth and Bottom (1977) indicated that in order to describe the behavior of an individual driver, it was necessary to obtain repeated measurements on the same driver. Two different ways were used for data collection. In the first method, an intersection which was used by a significant number of drivers leaving a private work car park was selected. This intersection was filmed during the evening peak hour using time-laps photography on 79 evenings. Sufficient data were available for analyses on 16 drivers. At the same intersection six experimental driver drove through the intersection about 100 times each. Data were recorded again using time-lapse photography.

Radwan and Sinha (1980) also used the time-motion picture technique. Teply (1984) used a similar approach that has been previously used by Kockelke in 1971 for evaluating individual driver behaviour in space and time with respect to safety and capacity. The procedure includes filming merging area of freeway ramp using 16-mm camera with zoom lens and speed of 24 frames per second. A movement analyzer was used for data extraction from the film. The longitudinal and lateral displacements of vehicles were calculated second by second and were plotted (vehicle trajectories) and

analyzed. The research concluded that the survey of vehicle trajectories provided a valuable objective method for measuring and evaluating driver behaviour.

2- Events Pen Recorder Actuated Either by the Observer or by Road Tubes/ Cables

Wagner (1966) used two observers to operate a special survey device consisting of 10 push-button microswitches which were electrically connected to a multiple-pen event recorder. The observer manually actuated the switches to denote: the arrival of main street vehicles, by direction, the arrival of side street vehicles, by direction and vehicle type, and the entry of side street vehicles into the intersection, by direction and turning manoeuver. This allowed gap and lag size and acceptability data to be extracted from the chart recorder. Gap and lag size data were separated into 1-second intervals. For each interval the observed percent acceptance was computed.

Darzentas et al. (1980) collected data at T-junctions. The arrival times of main street vehicles as well as their speed were recorded using coaxial cables laid in the main road. One observer recorded type of main road vehicle (car/other) and whether or not head lights were in use. A second observer recorded the arrival and departure of side road turning vehicle as well as the numerical part of the side road vehicle number plate. The two observers record the data using handset input devices. All data from cables or observers were combined with a clock time and stored on a magnetic tape cassette for subsequent analysis.

Maze (1981) used three observers to record gap acceptance. Two observers operated hand-hold switches. One of these two observers recorded a signal whenever a main stream vehicle entered the intersection. The second observer recorded the acceptance of gap by minor stream vehicle. The third observer measured the length of the minor stream queue at one minute intervals. The data were stored on a magnetic tape (casette) with time flag. The data were transferred to a computer disk and then formatted for analysis.

Uber (1976) collected data at T-junctions. Speeds of approaching vehicles were measured by a traffic radar. A road tube with air switch provided the arrival times and headway sizes of near side major road vehicles, which were recorded by an event pen

recorder. Hand operated switch operated other event pens to record the arrival and departure time of minor road vehicles.

Adebisi and Sama (1989) used a three-pen recorder for the observation. The first pen was connected by an automatic counter to a pneumatic tube stretched across the far traffic lane to get information about vehicle arrival and headways between vehicles on the far traffic lane. The second pen was connected to a portable battery with a manually operated switch that recorded the arrival at the intersection of the near lane traffic as well as headways. The third pen was used to monitor the time of arrival and departure of minor road vehicle which indicate the rejected, accepted gap and the duration of stopped delay experienced by each minor road driver.

3- Controlled Field Experiment

Gibbs (1968) did an experimental controlled field test on four drivers using the method of constant stimuli. Two vehicles were used, one was parked at an intersection while the other was the stimulus vehicle (the approaching vehicle). The driver was seated in the parked vehicle while his vision was restricted by an electrically operated shutter mounted in the driver's side window of the vehicle. The preset times for shutter opening were determined to allow different gap size with 1.2 sec. increments. Different approach speeds were used for the stimulus vehicle. The driver in the parked vehicle was asked to observe the approaching vehicle when the shutter was opened. The driver had to judge whether or not he would accept the gap and cross through the intersection.

4- Laboratory Driving Simulation Experiments

Ebbesen et al. (1977) conducted two types of experiments. A laboratory simulation experiment and a field experiment. In the laboratory simulation experiment two model cars traveled on specially designed tracks. One track was traversed by the subject's car at a constant velocity. The approaching car traveled along another track perpendicular to the track along which the subject's car travelled. The velocity of the approaching car was set at certain predetermined levels. The starting distance of the approaching car was set at different distances away from the intersection of the two tracks. The subjects, after seeing the distance and velocity of the approaching car, had to decide whether it was safe enough to cross in front of approaching car or not. The same test was used again and the subjects

were asked to judge how risky it would have been to have crossed in front of the approaching car. Subjects made risk judgements on continuous 200-mm scale ranged from extremely risky to not risky. The field experiments were done by observing the behavior of drivers making left turns at T-intersection. The velocity and distance of an approaching car were measured. The temporal gap was measured using a stopwatch. Whether or not a subject turned in front of it was recorded.

Hancock et al. (1991) used a closed-loop, interactive, fixed-base driving simulator. Drivers were located near an intersection and instructed to turn left across a stream of on-coming traffic when they felt that it was safe for them to do so. The on-coming stream of traffic was varied in terms of approach speed, inter-vehicle time interval, and vehicle type.

5- Closed Circuit Television or Video Camera,

Cooper et al. (1976) used a closed-circuit television to film drivers turning left from minor street and merging with the through main street traffic. Gaps were later measured from the film using a stopwatch. The speeds of main road vehicles were obtained using pneumatic tubes. Observations were made on several weekdays during the morning peak-hour.

Polus (1983) used a video-tape camera fitted with a zoom lens for data collection. A digital clock was fitted into the photographic system. Approach speeds, gap and lag times, and delay times were calculated. Owing to the depth of field limitation of the video camera as well as to practical limits for a gap or lag size, the upper limit of any lag or gap was set at 16 seconds.

Kyte et al. (1991) collected the data by video taping the chosen sites with a camera. Data collection software "TDIP" (Kyte and Boesen 1989) was used to record the following data while observing the videotapes: the time that each major traffic stream vehicle entered the intersection, the time at which the minor stream vehicle arrived at the end of the queue, arrived at the stop line and entered the intersection. The same data collection procedures have been use before in research which was undertaken at the University of Alberta (Chan and Teply 1991) to estimate traffic accident potential at stop-

controlled T-intersections by using delay. Fitzpatrick (1991) and Lassarre et al. (1991) also used the video taping technique for data collection.

6- Lap Top Computer

Kittelson and Vandehey (1991) collected data by means of a laptop computer programmed to accept keystrokes which identified the arrival and/or departure of vehicles on each major and minor movement in a real time. that each such arrival and/or departure occurred. The data were recorded on diskettes and latter analyzed using an additional customized computer program. The following data were collected: The arrival time of the vehicle at the front of the queue, the vehicle's departure time, the length of accepted gaps, and the number of rejected gaps longer than the accepted one.

RELATED RESEARCH ON DRIVER TRAFFIC SAFETY BEHAVIOUR

Blomquist (1986) presented a theoretical formulation of risk compensation using utility maximization approach as a tool to understand driver traffic safety behaviour. The basis of the utility maximization model is that the driver has safety and non safety goals and driver has some control over safety. Because individuals face scarcity of time, energy and money and because there are several ways to achieve goals, individual must make choices. The individual will seek to maximize utility of goals and means within the limits of personal resources. Driver's safety effort is determined by a balance between risk and disutility cost. External changes which affect the balance lead drivers to change their own safety efforts. The proposed utility function is given as follows:

$$U = I - D(e,s) - P(e,s)*L(e,s)$$

Where U = expected utility,

I = income which represent motorist resource constraint,

D(e,s) = disutility, associated with driver safety effort (e) and external safety factors (s) which are beyond his immediate control,

P(e,s) = the probability that a motorist is involved in an accident, influenced by e, s,

e = driver effort, can involve time, inconvenience, energy, and money,

L = the loss which the motorist incurs given that an accident occurs that depends on e and s.

The previous equation shows that the expected utility equals the income less disutility less the expected accident loss. Balance occurs when:

$$dU/de = 0$$
$$-D_e = P_e L_e + P L_e$$

The optimal driver safety effort is determined by a balance between disutility cost and reduction in expected loss. Changes in any factors which affect disutility or expected loss will change optimal safety effort. For example, change in geometric design to upgrade a roadway into highway will increase probability of accident (P) and induce an increase in driver safety effort. Any changes that increase the loss in an accident (L) such as driving a car with the family will increase safety effort. Conclusion is that risk compensation (offsetting behaviour) is a normal response to change in safety environment.

RELATED TIME PERCEPTION LITERATURE

Gibson (1979) stated that events are perceived, but time is not. He also stated that time is not another dimension of space and the reality underlying the dimension of time is the sequential order of events and we should begin thinking of events as the primary realities and of time as an abstraction from them. Woodrow (1951) stated that time is not a thing that, like an apple, may be perceived. Stimuli and patterns of stimuli occupy physical time; and we react to such stimuli by perceptions, judgments, comparisons, and estimates. Woodrow also mentioned that time is a concept, somewhat like the value of pieces of money, that attaches to perceptions only through judgmental process. The ease and apparent immediacy of the temporal judgment in certain cases might be explained as the result of practice.

In case of gap acceptance situation, there is more than one time dimension. One time dimension represents the perceived time gap between two successive opposing vehicles. Another time dimension is the perceived delay (queue delay and/or front delay). Third time dimension is the amount of time saving as a result of accepting a gap. This research hypothesizes that driver makes the decision to accept or reject a gap by comparing a value of time saving with a value assigned to the risk of accepting a gap. The value of time saving differs by individuals, purpose of trip and time of the day.

The Canadian Capacity Guide for Signalized Intersections (Teply 1984) employed an empirical relationship for saturation flow for left turning traffic penetrating through traffic in the opposing direction. The data were collected using multi-channel traffic event recorder and voice recorder. The developed relationship in Edmonton is as follows:

$$S_L = 1650\, e^{-0.00112\, V6}$$

Where S_L = left turn saturation flow (pcu/h green),

Vó = rate of opposing traffic flow (pcu/h green) during the period when the left turns are permitted to penetrate.

A similar relationship was developed in Edmonton for the right turning traffic with pedestrian interference (Poss 1985). This relationship is as follows:

$$S_R = 1450\, e^{-0.001\, v'_{ped}}$$

Where S_R = right-turn saturation flow (pcu/h green),

v'_{ped} = converted pedestrian volume (ped/h green).

This relationship was modified by Teply (1990) as follows:

$$S_R = 775 - .189\, v'_{ped}$$

Comparing the saturation flow equations for right turn with that for the left turn, one notices that the saturation flow trend in both cases is the same. One might speculate that the driver perceives the danger of being involved in accident and not the kind or the severity of accident.

Chan and Teply (1991) showed that there is a possibility of using delay to predict accidents at unsignalized intersections. This result supports the fact that as drivers are delayed waiting for an acceptable gap, they tend to accept a smaller gap which could increase the number of accident and affect driver's safety.

APPENDIX B

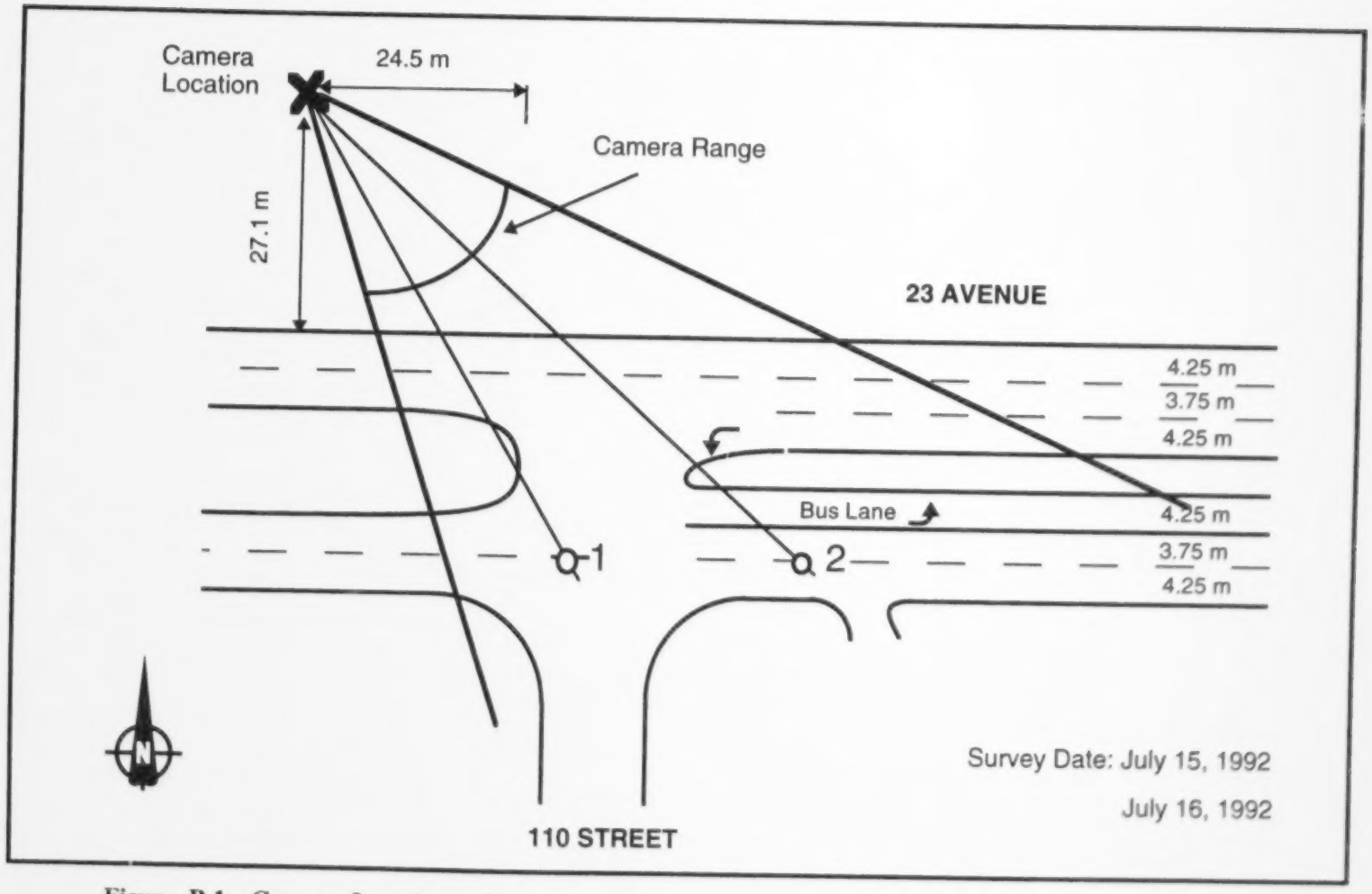

Figure B.1 Camera Location at 23 Avenue Intersection

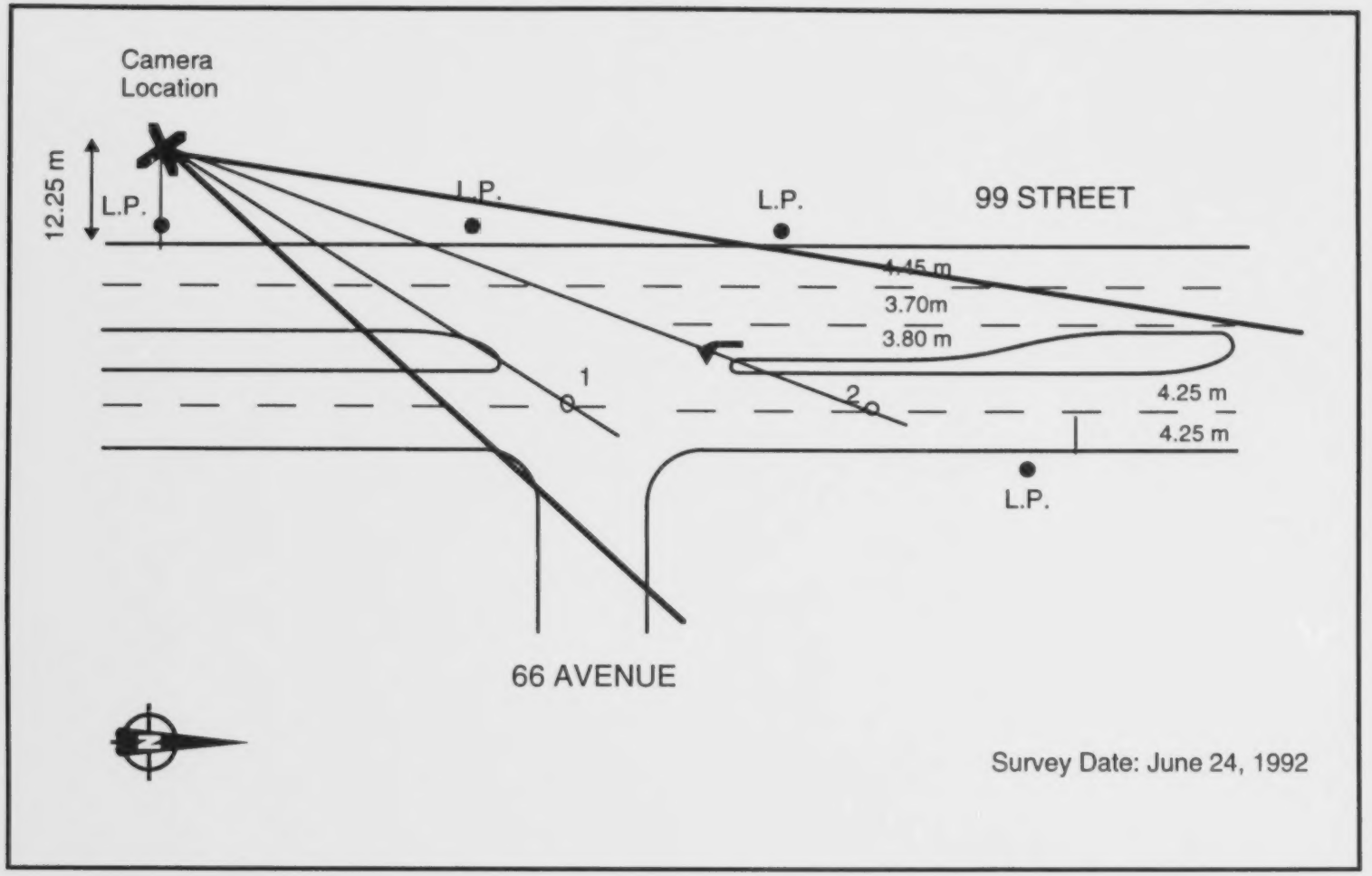

Figure B.2 Camera Location at 99 Street Intersection (A)

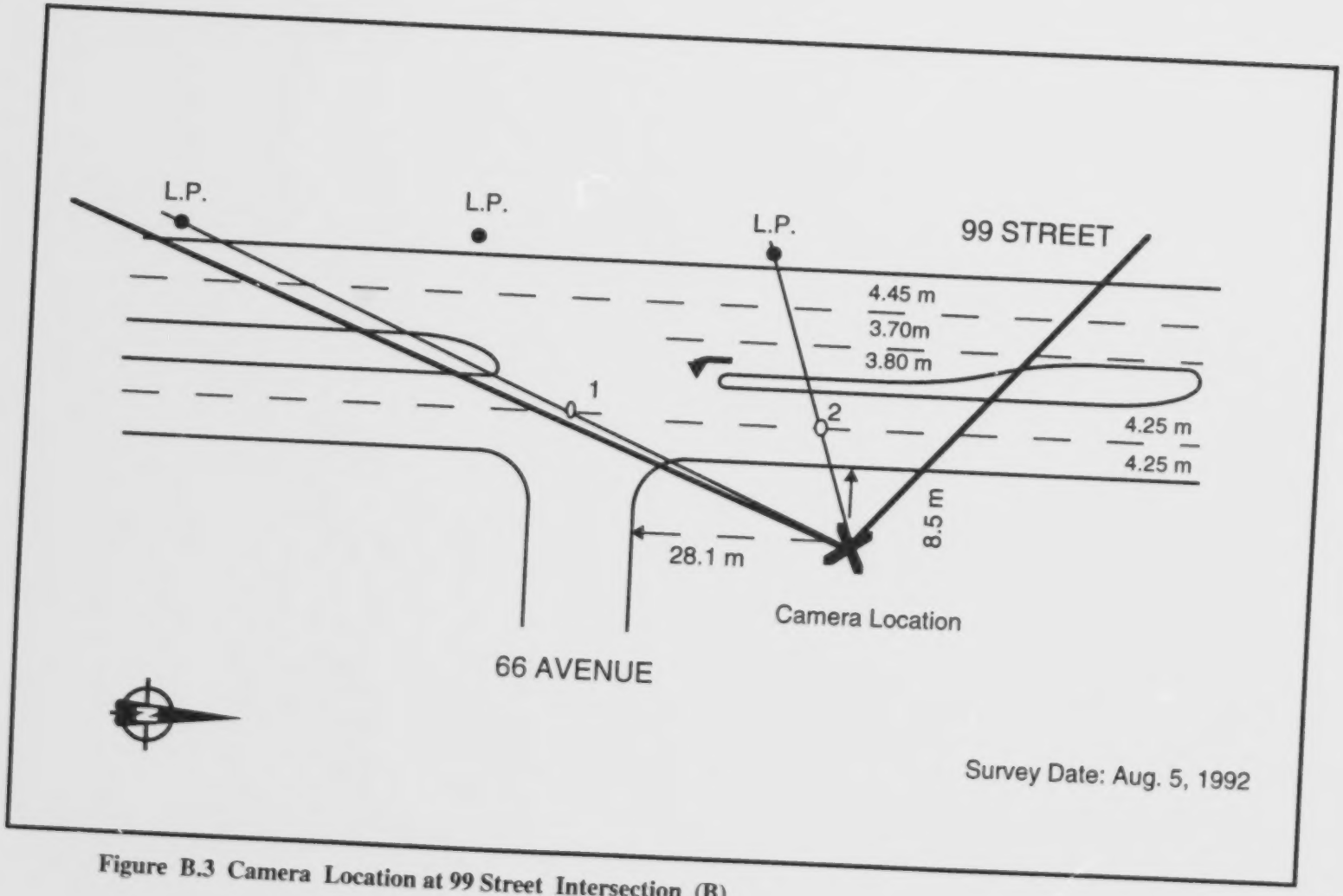

Figure B.3 Camera Location at 99 Street Intersection (B)

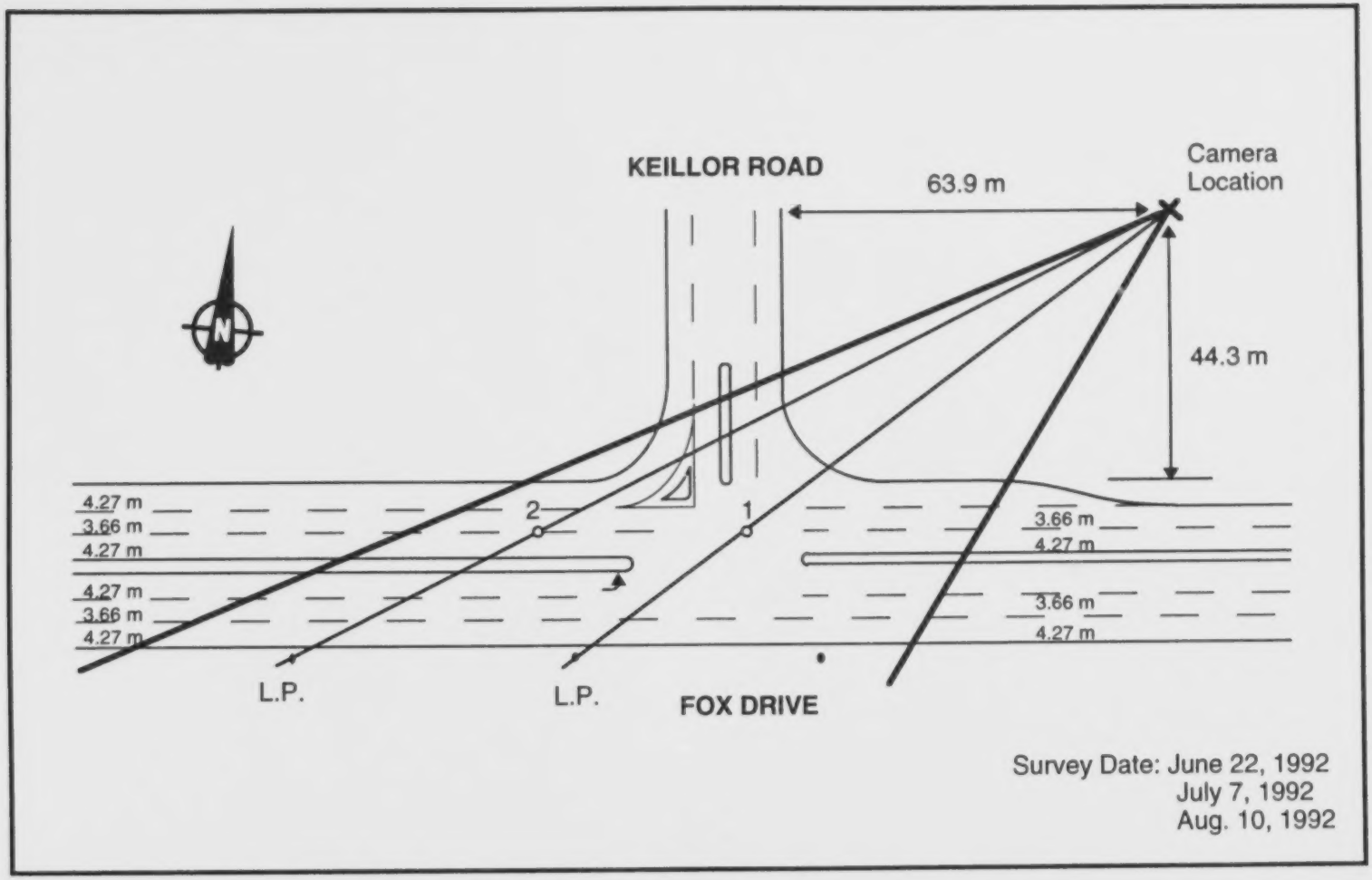

Figure B.4 Camera Location at Keillor Road Intersection (A)

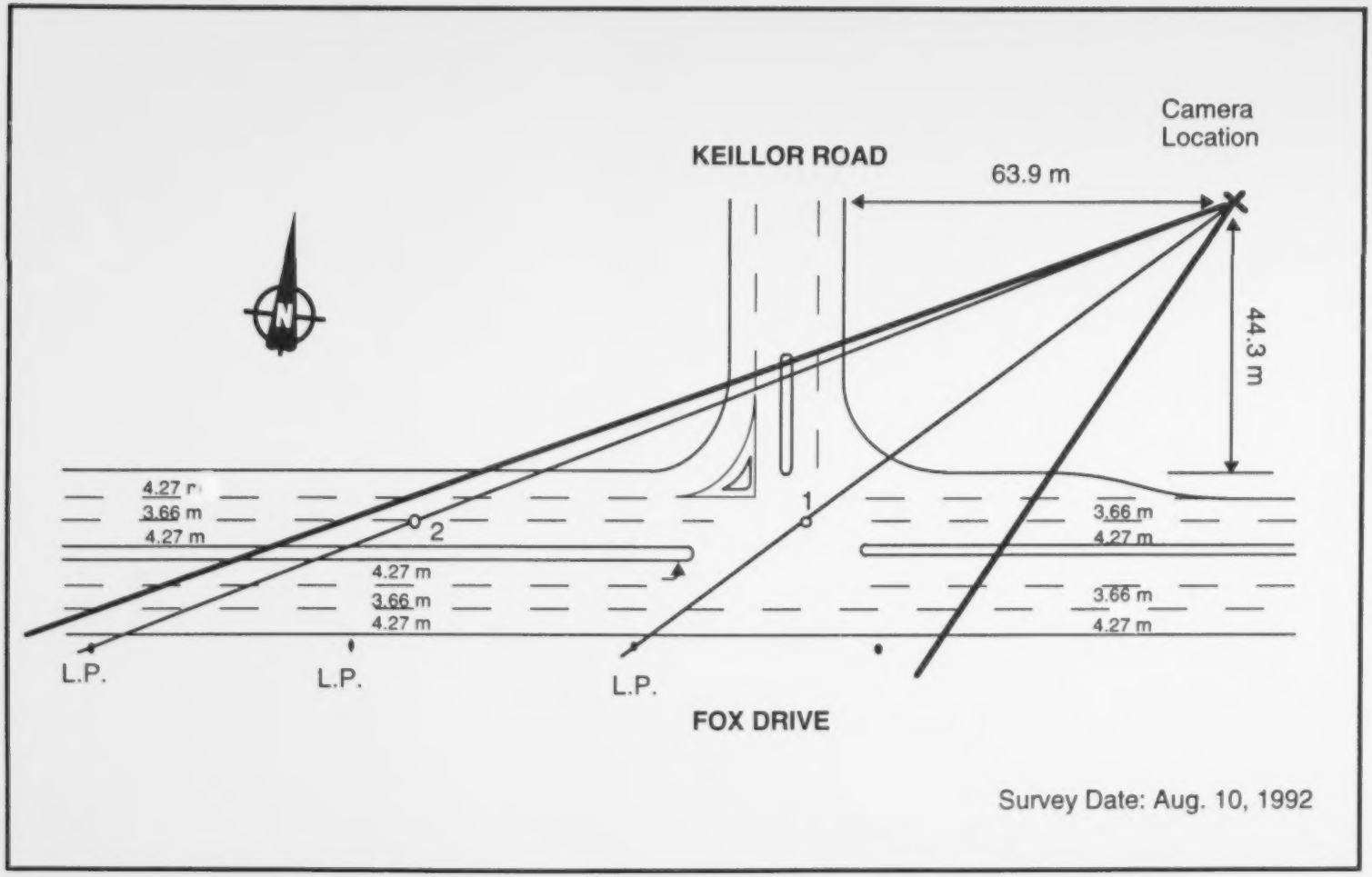

Figure B.5 Camera Location at Keillor Road Intersection (B)

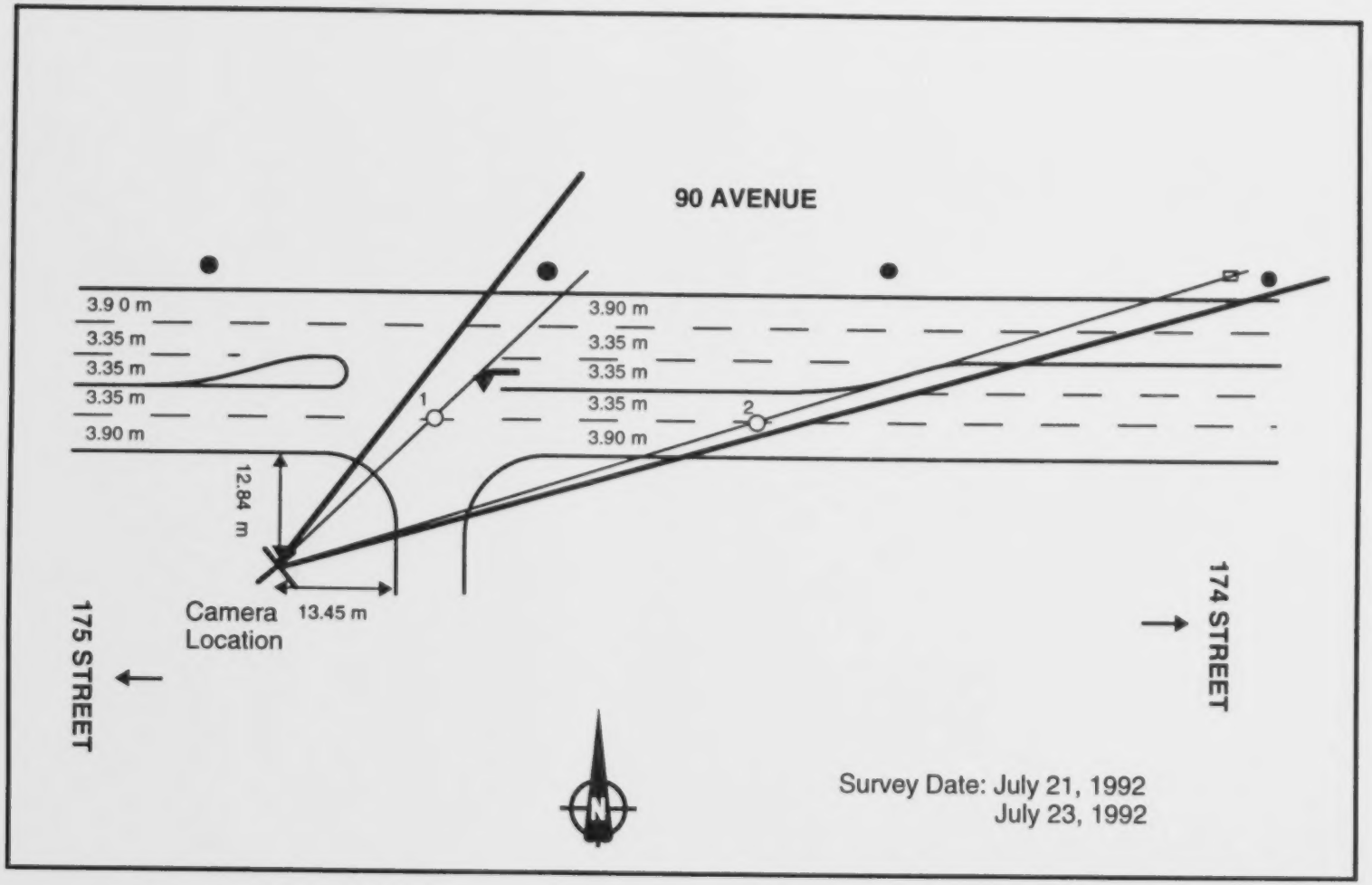

Figure B.6 Camera Location at West Edmonton Mall Intersection (A)

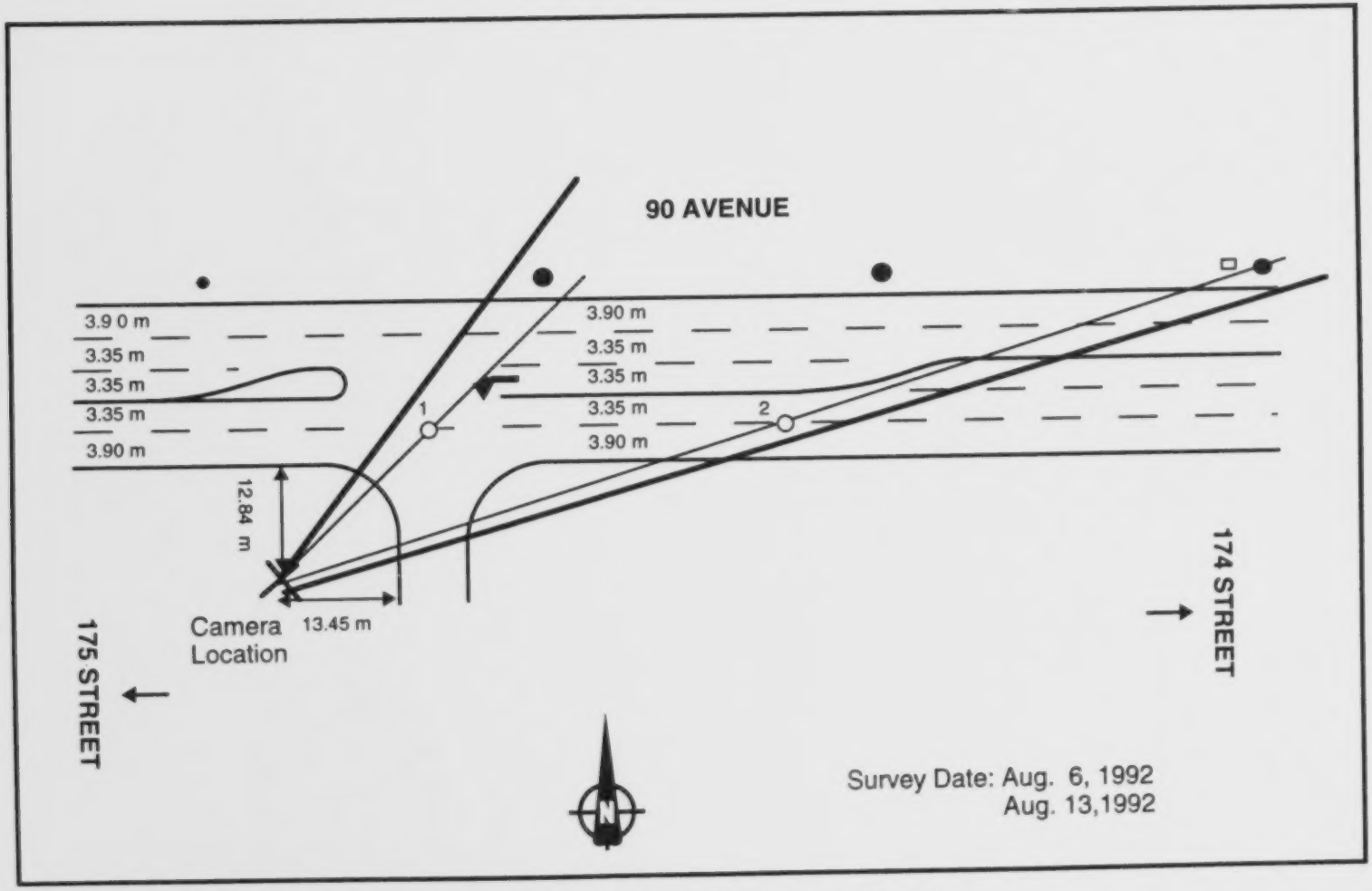

Figure B.7 Camera Location at West Edmonton Mall Intersection (B)

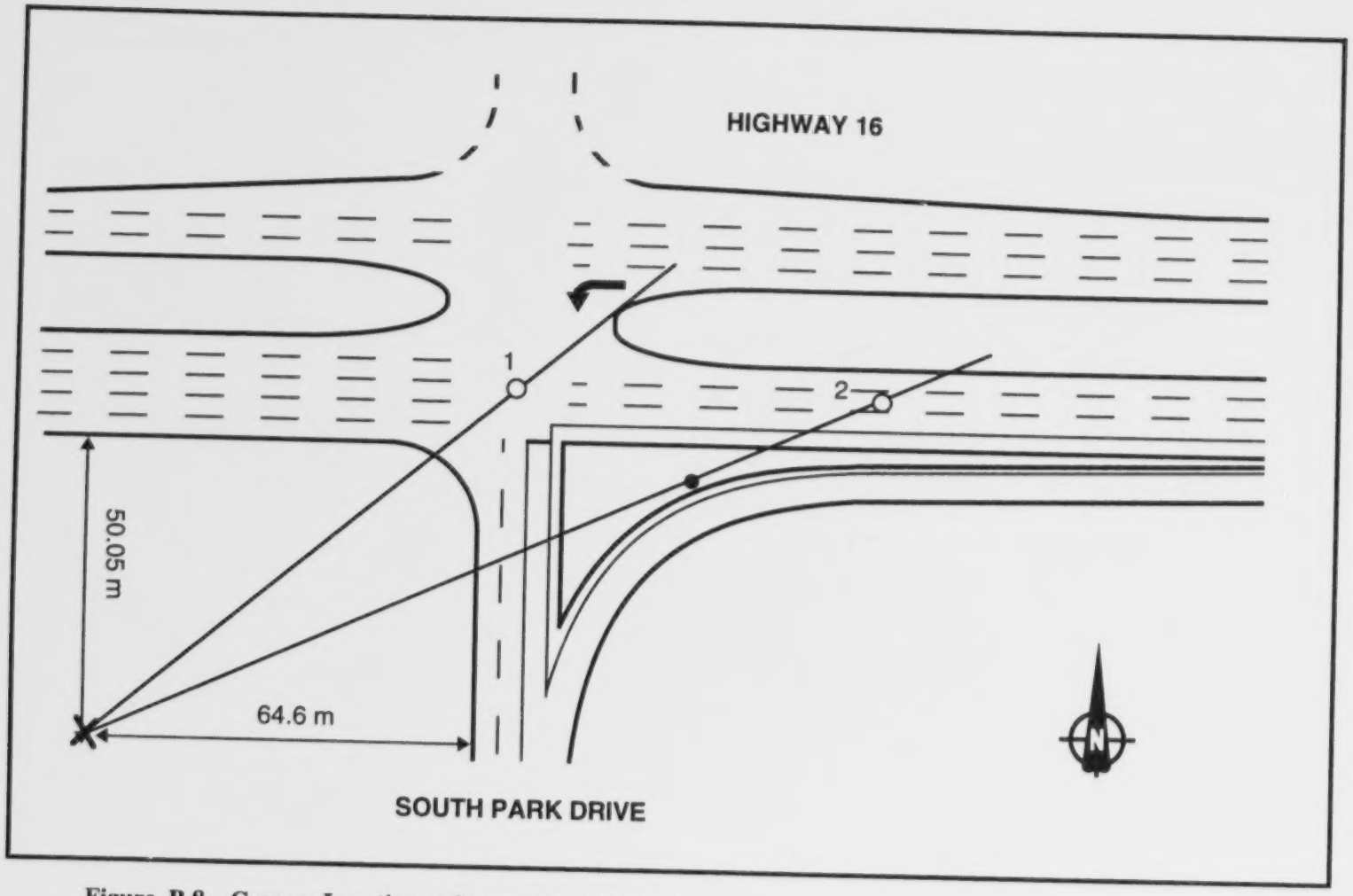

Figure B.8 Camera Location at Stony Plain Intersection

APPENDIX C

```
**************************************************************************
   PROGRAM TO CALCULATE FOR EACH TURNING VEHICLE: GAP, SPEED,
QUEUE  DELAY, FRONT DELAY,  and  OTHER VARIABLES  (ENTRY
REQUIRED TO LOGIT PROGRAM)
**************************************************************************

   IMPLICIT REAL *8(A-H, O-Z)
   CHARACTER * 12 FIN1, FIN2, FOUT1, FOUT2
   DIMENSION ARRIV1(1630), SPEED(1630), ENTER(610), GAP(50), FDELAY(
   X50), IVBEH(50),IP(1630),IBT(1630),M(1630),SGAP(50),TDELAY(50)
   IN1 = 7
   IN2 = 8
   IOUT2 = 11

   WRITE (*,*) 'ENTER INPUT FILE NAME FOR THROUGH TRAFFIC'
   READ (*, '(A)') FIN1
   WRITE (*,*) 'ENTER INPUT FILE NAME FOR LEFT TURN TRAFFIC'
   READ (*,'(A)') FIN2
   WRITE (*,*) 'ENTER SECOND OUTPUT FILE NAME'
   READ (*, '(A)') FOUT2
   OPEN (UNIT = IN1, FILE = FIN1, STATUS = 'OLD')
   OPEN (UNIT = IN2, FILE = FIN2, STATUS = 'OLD')
   OPEN (UNIT = IOUT2, FILE = FOUT2, STATUS = 'NEW'

   NUMVT = TOTAL NUMBER OF THROUGH VEHICLES
   NUMT  = THROUGH VEHICLE NUMBER
   ARRIVI(I) = ARRIVAL TIME OF THROUGH VEHICLE AT POINT 1
   ARRIV2    = ARRIVAL TIME OF THROUGH VEHICLE AT POINT 2
   SPEED (I) = SPEED OF THROUGH VEHICLES
   IP(I)= 1 IF THROUGH VEHICLE WAS PASSENGER CAR, =0 OTHERWISE
   IBT(I)= 1 IF THROUGH VEHICLE WAS BUS OR TRUCK, =0 OTHERWISE
   M(I) = 1 IF THROUGH VEHICLE WAS MOTORCYCLE, =0 OTHERWISE
```

```
      READ (IN1, *) DIST, NUMVT

      DO 100 I = 1, NUMVT
      READ (IN1, *) NUMT, ARRIV1(I), ARRIV2,IP(I),IBT(I),M(I)
      SPEED(I) = DIST/((ARRIV2 - ARRIV1(I)) * 24*1000)

100   CONTINUE

      NUMVL = TOTAL NUMBER OF LEFT TURNING VEHICLES
      NUML  = LEFT TURN VEHICLE NUMBER
      SEX   = SEX OF LEFT TURNING DRIVER (M=MALE, F=FEMALE)
      AGE   = AGE GROUP OF LEFT TURNING DRIVER (Y=YOUNG, M=MIDDLE,
              O=OLD)
      PAS.  = PRESENCE OF PASSENGERS IN TURNING VEHICLE (Y=YES, N=No)
      ACC. CAPABIL = ACCELERATION CAPABILITY CATEGORY OF THE
                     TURNING VEHICLE  (S=LOW,  A=AVERAGE,  F=HIGH)
                     LOW = 1 IF LOW,  =0 OTHERWISE
                     AVE = 1 IF AVERAGE,  =0 OTHERWISE
      ENTER(J) = TIME WHEN LEFT TURNING VEHICLE JOIN THE QUEUE
      WAIT  = TIME WHEN TURNING VEHICLE BECOME THE FIRST VEHICLE IN
                  THE QUEUE WAITING FOR A GAP BETWEEN THE MAIN
STREAM                    VEHICLES
      DEPART = TIME WHEN LEFT TURNING VEHICLE CROSS THE CONFLICT
               POINT (POINT1)
      OPPOS. TYPE = TYPE OF OPPOSING VEHICLE (P= PASSENGER CAR,
                        B/T=BUS/TRUCK,  M=MOTORCYCLE,  BI=BIKE)
      #REJ = NUMBER OF REJECTED GAPS
      VEHBEH = PRESENCE OF VEHICLES BEHINED THE TURNING
ONE.(Y=YES,                       N = NO)
      FLOW = MICROSCOPIC FLOW RATE
      TGAP = TIME GAP
      QDELAY = QUEUE DELAY
      FDELAY = FRONT OF QUEUE DELAY
      ID = LOCATION IDENTIFICATION NUMBER
```

```
      READ (IN2, *) NUMVL
      DO 180  J=1, NUMVL
      READ (IN2, *) NUML, ENTER

180   CONTINUE

      CLOSE (IN2, STATUS = 'KEEP')
      OPEN (UNIT = IN2, FILE = FIN2, STATUS = 'OLD')
      READ (IN2, *) NUMVL,ID, NLANES, WIDTH

      IGROUP =ID
      DO 200  J=1,  NUMVL

      READ (IN2, *) NUML, ENTER(J), WAIT, DEPART, ISEX, IYOUNG, MIDDLE,
     XIPASS, LOW, IAVER

      QDELAY = (WAIT - ENTER(J))*24*60*60
      I = 1

220   IF (ARRIV1(I) - WAIT  .LT. 0.0) THEN
       I = I + 1
       GO TO 220
      ELSE
       K = 1
       GAP(K) = (ARRIV1(I) - WAIT) *24*60*60
       IF (J+1 .GT. NUMVL) THEN
       IVBEH(K)=0
       GO TO 230
       ELSE
       GO TO 225
       ENDIF
```

```
225    IF (ENTER(J+1) -WAIT .LT. 0.00) THEN
       IVBEH(K) = 1
      ELSE
       IVBEH(K)=0
      ENDIF

230   IF (DEPART - ARRIV1(I) .LT. 0.00) THEN
      FLOW = K/((ARRIV1(I) - WAIT) *24*60)
      M2 = I
      GO TO 250
     ELSE
      K = K+1
      FDELAY(K) = (FDELAY(K-1) + GAP(K-1))
      GAP(K) = (ARRIV1(I+1) - ARRIV1(I)) *24*60*60

    IF (ENTER(J+1) - ARRIV1(I) .LT. 0.00) THEN
     IVBEH(K) = 1
    ELSE
     IVBEH(K) = 0
    ENDIF
      I = I+1
      GO TO 230
     ENDIF
    ENDIF

250  DO 400  N=1, K
     I1=I-K+1
     L= N-1
    L = # OF REJECTED GAPS
     SGAP(N) = GAP(N)*SPEED(I1)/3.6
     TDELAY(N) = QDELAY + FDELAY(N)
    SGAP = SPACE GAP SIZE
    TDELAY = TOTAL DELAY = QDELAY +FDELAY

    I = I+1
400  CONTINUE
```

```
**************************************************************************
   FORMAT THE DATA AS REQUIRED BY NTELOGIT PROGRAM
**************************************************************************
    IF (K .EQ. 1) GO TO 450
     DO 500  N=1, K-1
      I1=M2-K+1
      L=N-1
     WRITE (IOUT2, 310)
IGROUP,ISEX,IYOUNG,MIDDLE,IPASS,LOW,IAVER,QDELA
   XY,FDELAY(N),TDELAY(N),GAP(N),SPEED(I1),SGAP(N),IP(I1),IBT(I1),M(I1
   X),L,FLOW,IVBEH(N),NLANES,WIDTH,IGROUP,

310   FORMAT ( I8,'  1  0  1',6I4,4F8.2,F6.0,F8.2,3I4,I5,F8.2,2I4,F8.2
   X / I8,' 2  1  0  0  0  0  0  0  0  0     0     0     0
   x    0  0      0   0  0  0  0  0     0  0  0  0')

      M2=M2+1
      IGROUP=IGROUP+1
500  CONTINUE

450  N=K
    L=N-1
    I1=M2-K+1
    WRITE (IOUT2, 320)
IGROUP,ISEX,IYOUNG,MIDDLE,IPASS,LOW,IAVER,QDELA
   XY,FDELAY(N),TDELAY(N),GAP(N),SPEED(I1),SGAP(N),IP(I1),IBT(I1),M(I1
   X),L,FLOW,IVBEH(N),NLANES,WIDTH,IGROUP,

320   FORMAT ( I8,'  1  1  1',6I4,4F8.2,F6.0,F8.2,3I4,I5,F8.2,2I4,F8.2
   X / I8,' 2  0  0  0  0  0  0  0  0  0     0     0     0
   x    0  0      0   0  0  0  0  0     0  0  0  0')
    IGROUP=IGROUP+1

200  CONTINUE
    STOP
    END
```

Table C.1 Example of Input Data File to Logit Estimation Program

30125	1	1	1	1	0	0	0	0	1	19.87	0	19.87	6.65	64	118.58	1	0	0	0	9.02	0	2	8
30125	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30126	1	0	1	1	0	1	0	0	0	0.35	0	0.35	2.25	70	43.52	1	0	0	0	12.86	0	2	8
30126	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30127	1	0	1	1	0	1	0	0	0	0.35	2.25	2.59	2.85	42	33.43	1	0	0	1	12.86	0	2	8
30127	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30128	1	1	1	1	0	1	0	0	0	0.35	5.1	5.44	8.9	53	132.18	1	0	0	2	12.86	1	2	8
30128	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30129	1	0	1	0	1	0	1	0	1	5.36	0	5.36	5.79	53	85.98	1	0	0	0	6.94	0	2	8
30129	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30130	1	1	1	0	1	0	1	0	1	5.36	5.79	11.15	11.49	53	170.68	1	0	0	1	6.94	0	2	8
30130	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30131	1	1	1	0	0	1	0	0	1	0.26	0	0.26	23.5	70	455.3	1	0	0	0	2.55	0	2	8
30131	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Column 1: Group identification number

Column 2: Alternative number; alternative 1= accept a gap, and alternative 2 = reject a gap

Column 3: Choice frequency, = 1 if an alternative chosen, and = 0 if not chosen

Table C.2 Group Identification Numbers for Each Observation Period

Location	Observation date	Group identification number start with
23 Avenue	- July 15, 1992 (PM peak)	10001
	- July 16, 1992 (PM peak)	20001
99 Street	- June 24, 1992 (PM peak)	30001
	- Aug. 5, 1992 (PM peak)	40001
Keillor Road	- June 22, 1992 (PM peak)	50001
	- July 7, 1992 (AM off-peak)	60001
	- Aug. 10, 1992 (PM off-peak)	70001
	- Aug. 10, 1992 (PM peak)	80001
West Edmonton Mall	- July 21, 1992 (PM peak)	90001
	- July 23, 1992 (PM peak)	100001
	- Aug. 6, 1992 (PM off-peak)	110001
	- Aug. 6, 1992 (PM peak)	120001
	- Aug. 13, 1992 (AM off-peak)	130001
Stony Plain	- Aug. 11, 1992 (PM peak)	140001

APPENDIX D

Statistical Tests Supplementary to Chapter 5

Testing the Linear Relationship between Front Delay Parameters of Model 2 in Table 6.12.

Null hypothesis $\beta_i = \beta_{i-1}$

$$\text{t-ratio} = \frac{\beta_i - \beta_{i-1}}{\sqrt{\text{var}(\beta_i) + \text{var}(\beta_{i-1}) - 2\text{cov}(\beta_i, \beta_{i-1})}}$$

If t-ratio >1.65 (or 1.96), it would be possible to reject the null hypothesis of linear relationship between parameters at 90 (or 95 %) confidence level. Table D.1 list the calculated t-statistics test.

Table D.1 The t-statistics of the Null Hypothesis of Linear Relationship Between Front Delay Parameters of Model 2 in Table 6.12

Fdelay variable	βi	Var.	Cov. (βi & βi-1)	t-ratio * (βi & βi-1)
F 0-5	-0.31486	0.001263		
F5-10	0.02878	0.003274	-0.00119	-4.135
F10-15	-0.07219	0.00754	-0.00302	0.778
F15-20	0.029587	0.016642	-0.00715	-0.519
F20-25	-0.2348	0.036061	-0.01571	0.912
F25-30	-0.60148	0.146	-0.03785	0.722
F30-35	0.584013	0.178695	-0.13712	-1.532
F35-40	0.024541	0.109108	-0.07473	0.846
F40-45	0.147546	0.10938	-0.0742	-0.203
F>45	0.106058	0.009461	-0.01863	0.105

Testing the values of t-ratio in Table D.1, some of front delay variables can be combined as following:

F10-15 and F15-20

F20-25 and F25-30

F40-45 and F>45 This combination is tried as shown in Model 3 in Table 6.12.

Table D.2 shows the result of t-ratio test of the null hypothesis of linear relationship between front delay parameters of Model 3 in Table 6.12.

Table D.2 The t-statistics of the Null Hypothesis of Linear Relationship Between Front Delay Parameters of Model model 3 in Table 6.12

Fdelay variable	βi	Var. (βi)	Cov. (βi & βi-1)	t-ratio * (βi & βi-1)
F0-5	-0.31221	0.001245		
F5-10	0.12524	0.002767	-0.00109	-5.560
F10-20	-0.02162	0.001775	-0.00131	1.735
F20-30	-0.30139	0.010711	-0.0023	2.140
F30-35	0.31886	0.077242	-0.02101	-1.720
F35-40	0.094063	0.066514	-0.04599	0.463
F>40	0.11139	0.004365	-0.00896	-0.058

Looking at the values of t-ratio in Table D.2, some of front delay variables can be combined as following:

F5-10 and F10-20

F30-35, F35-40 and F>40 This combination is tried as Model 4 in Table 6.12.

Also different combination of front delay variables is possible according to the same result of testing parameters of Model 2 Table 6.12) as follows:

F5-10 and F10-F15

F15-20 and F20-F25

F30-35 and F35-40

F40-45 and F>45 This combination is shown as Model 5 in Table 6.12.

Table D.3 shows the result of t-ratio test of the null hypothesis of linear relationship between front delay parameters of Model 5 in Table 6.12.

Table D.3 The t-statistics of the Null Hypothesis of Linear Relationship Between Front Delay Parameters of Model 5 in Table 6.12

Fdelay variable	βi	Var. (βi)	Cov. (βi & βi-1)	t-ratio * (βi & βi-1)
F0-5	-0.30642	0.001073		
F5-15	-0.00112	0.000812	-0.0005	-5.680
F15-25	-0.09544	0.003209	-0.00086	1.244
F25-30	-0.49416	0.057656	-0.00647	1.468
F30-40	0.257617	0.02006	-0.028	-2.056
F>40	0.094329	0.004016	-0.0045	0.898

Examining t- ratio value of Table D.3 (of model 5), the following combination of front delay variables is possible:

F30-40 and F>40 This combination has been tried as in Model 6 in Table 6.12.

The variance-conariance matrix information was used to test the linear relationship between Fdelay variables of Model 7 (Table 6.13) is shown in Table D.4

Table D.4 The t-ratio of Null Hypothesis of Linear Relationship between parameters of model 7

Fdelay variable	βi	Var. (βi)	Cov. (βi & βi-1)	t-ratio * (βi & βi-1)
b0-1.5	-0.78442	0.017836		
b1.5-5	-0.05516	0.006175	-0.0078	-3.664
b5-10	-0.06175	0.003883	-0.00287	0.052
b10-15	-0.03719	0.007652	-0.00328	-0.183
b15-20	0.143075	0.016737	-0.0072	-0.915
b20-25	-0.23277	0.036328	-0.01582	1.291
b25-30	-0.60576	0.147094	-0.03814	0.732
b30-35	0.591358	0.179934	-0.13819	-1.541
b35-40	0.016919	0.109194	-0.07512	0.867
b40-45	0.151422	0.109562	-0.07421	-0.222
b>45	0.108834	0.009494	-0.01871	0.108

For front delay intervals, the following combination is possible:

F1.5 -5 , F5-10, and F10-15
F35-40, F40-45, and F>45 This combination is shown in Model 8 in Table 6.13.

Table D.5 shows the t-ratio of null hypothesis of linear relationship among parameters of model 9

Table D.5 The t-ratio of Null Hypothesis of Linear Relationship Among Parameters of Model 8 in Table 6.13

Fdelay variable	βi	Var. (βi)	Cov. (βi & βi-1)	t-ratio * (βi & βi-1)
F0-1.5	-0.78855	0.009965		
F1.5-15	-0.05427	0.000449	-0.00121	-6.480
F15-20	0.030031	0.011279	-0.00111	-0.714
F20-25	-0.24267	0.035058	-0.01329	1.010
F25-30	-0.57749	0.137817	-0.03649	0.675
F30-35	0.526828	0.12822	-0.11689	-1.562
F>35	0.105108	0.002445	-0.00689	1.110

Examining the t-ratio of front delay variables of model 8, the following combinations are possible:

F1.5 -15 and F15-20
F20-25 and F25-30 This combination is shown as in Model 9.

Table D.6 shows the t-ratio of null hypothesis of linear relationship among parameters of model 9 in Table 6.13.

Table D.6 The t-ratio of Null Hypothesis of Linear Relationship Among Parameters of Model 9 in Table 6.13.

Fdelay variable	βi	Var. (βi)	Cov. (βi & βi-1)	t-ratio * (βi & βi-1)
F0-1.5	-0.81808	0.009098		
F1.5-20	-0.04169	0.000267	-0.00082	-7.403
F20-30	-0.27384	0.008513	-0.0006	2.324
F30-35	0.281215	0.049032	-0.01655	-1.844
F>35	0.111031	0.002388	-0.00513	0.685

Examining the t-ratio of front delay variables of model 9, the following combination are possible:

F30-35 and F>35 This combination is shown as in Model 10 in Table 6.13.